ELECTRIC CLOCKS

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By F. HOPE-JONES, M.I.E.E., F.R.A.S.

With a Foreword by

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FOREWORD

THE application of electricity to Horology has taken the best part of a century to reach success. Electricity was more easily applied to other problems in connection with time than to clocks themselves. The electric chronograph originally invented by Professor Locke and Professor Mitchell, of America, in 1848, *has long been in use to facilitate astronomical observations for time. In the determination of longitude, the tiresome carriage of chronometers was long ago superseded by telegraphic signals, and in recent years the use of Wireless has made a further great simplification in these operations. Again, the distribution of time has for many years been made telegraphically, and is now broadcast into every house which possesses a radio set. Incidentally, with these progressive changes, Greenwich time or time differing from it by a definite number of hours or half-hours has gradually become the standard over nearly the whole world.*

The first men who applied electricity to clocks were electricians rather than horologists. Mr. Hope-Jones points out clearly the mistakes they made by not realising that a pendulum should be as free as possible, and that energy can only be given or taken from it without interfering with its time-going properties, to a very limited extent and at a particular phase. Mr. Hope-Jones has devoted himself to the application of electricity to clocks for the last 35 *years. He tells us that in* 1895 *when he read a paper to the British Horological Institute on an electric clock which took no energy from the pendulum, Lord Grimthorpe, its President, said "Electric clocks never answered in any practical sense, nor would anything but the strongest evidence, independent of the inventor, convince me*

that any independent pendulum directly maintained by electricity can succeed in keeping good time for any considerable period, and anyone who sets to work to invent electrical clocks must start with this axiom, that every now and then electricity will fail to lift anything, however small."

Great advances have been made since that time. Many clocks now-a-days depend on electric contacts. It is common practice, especially in the Standard Clocks of observatories, to use electric winding and control. They keep good time and the contacts, if they ever fail, only do so on the rarest occasions. In this achievement Mr. Hope-Jones and the Synchronome Company have taken a large part.

The development of a pendulum maintained in oscillation but freed from an escapement and clock train has been gradually perfected. The Synchronome Master Clock which has been widely used for many years, has quite recently been improved so that only one-seventh part of the small consumption of energy previously necessary to make good mechanical losses is now required.

Mr. Hope-Jones devotes several chapters to the beautiful "Shortt" clocks which are now in use at various observatories. Experience at Greenwich has shown that it is not an unreasonable hope that the regularity of the rotation of the earth may eventually be checked by electrically-operated clocks.

Mr. Hope-Jones gives an account of the real contributions of a few men to the application of electricity to Horology, and criticises their achievements without fear or favour, gives praise where he thinks it due, but does not hesitate to point out what he considers their weak points. The book is liberally illustrated, it is easy for a layman to follow the arguments, and is, I think, the only work which covers the whole field. The problem appears to be simple after *it has been solved.*

F. W. DYSON.

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ELECTRIC CLOCKS

CHAPTER I

THE one subject of outstanding interest in horology at present is, and indeed has been for some considerable time, the application of electricity to the science of time measurement. Electricity has distinguished itself in connection with clockmaking in two remarkable ways. In recent years the startling events of our profession have been the equipment of thousands of buildings with circuits of electrical impulse dials and the extraordinary advance in the science of pure time-keeping.

Watch and clock making may be said to date from the fifteenth century, though a few earlier relics are known. Until the introduction of the pendulum by Galileo and Huyghens in 1660, they were of one family, all controlled by a foliot or verge balance, the only real difference between a watch and a clock being its size.

But from that moment watches and clocks parted company, their paths of development diverged. The evolution of the modern watch and the story of the chronometer have been told by abler pens than mine and cannot concern us here. Their portability is the justification of their independence. Electricity cannot help them, except to make them self-winding, and that is simply not worth while.

With the aid of the pendulum, the development of the clock proceeded apace. The most fruitful age followed quickly upon the introduction of the pendulum and may be called the first half of the eighteenth century. That period covered the invention of all the

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more important escapements and the clock soon excelled the watch as a precision time-keeper.

The Graham dead-beat escapement appeared early in that period, and has held the field ever since as the most accurate until Riefler, of Munich, surpassed it in 1890, and supplied about four hundred to the world's observatories in the twenty years before the great war. Thus we see that the home and nursery of the science was British, but that there was a period of nearly two hundred years of stagnation, after which Germany took up the running.

This volume tells the story of the recapture of the record for England by the Free Pendulum Clock designed by Mr. W. H. Shortt, M.Inst.C.E., in collaboration with the Synchronome Company, Ltd., and based upon that system.

It is not easy to speak with becoming scientific restraint when announcing an achievement which fulfils the wildest dreams of the horologist and the ambitions of a lifetime, so we quote Professor W. de Sitter, the Astronomer, of Leyden, in the language of cold fact. He says (in *Nature* of January 21st, 1928):—

"One of these clocks has been left entirely to itself, being, however, kept under rigorous observation at Greenwich, during the greater part of a year, *and its rate has been absolutely invariable*. . . . It looks as if this clock could be depended upon to keep time within a few hundredths of a second for a period measured in years instead of weeks."

How has this result been achieved? Not, certainly, by the methods of the seventeenth and eighteenth centuries, not by the perfection of clock escapements, which then attained their highest development and had brought us to an impasse, but by the use of electricity. And let no one imagine that the result was achieved by "one touch of the magic wand"; on the other hand, half a century has been spent in experimenting, and the track has been strewn with hundreds of failures.

The first applications of electricity to horology were early Victorian and date from the invention of the telegraph. There is an interest attaching even to the earliest and crudest electric clocks by Bain and Wheatstone in 1840. It is proposed that I shall take you by the hand along the road through which the idea has wandered or progressed, that I shall lead you down the primrose paths of pleasing mechanical and electromechanical devices, just far enough to show you the inevitable blind alleys, and then take you up and over the hills of difficulty to the straight road of scientific principles which will bring us to our goal.

When first it was realised that if electricity is led round a piece of iron, it made a magnet of it, the idea of applying it to clocks was fairly obvious, and did not long remain unexpressed.

Alexander Bain, a mechanic associated with Sir Charles Wheatstone in 1840, took out a patent in October, that year, and he was undoubtedly first, but whether he derived some certain inspiration from his distinguished chief, we have no means of knowing. In this patent he makes claims which cover the whole field of self-winding, synchronising, and synchronous propulsion. In 1843 he published a pamphlet, "On the application of the electrical fluid to the useful arts," describing his system in which the pendulum bob carries a permanent magnet adapted to swing through coils fixed to the case; or, alternatively, a moving coil and a fixed magnet, for it matters not which, if there is relative motion in a magnetic field.

The supply of current and its reversal at each semi-vibration was effected by a little ivory and gold slider, higher up the pendulum, with the result that the pendulum bob was duly pulled backwards and forwards by electro-magnetism.

The good time-keeping of a pendulum is dependent more than anything else upon its being left alone to swing freely under the influence of gravity. Even the

interference due to a comparatively delicate escapement at the top end of the pendulum is a source of error, a fact which has always been well known, but which lay dormant for 200 years under the soporific effect of escapements which were accepted as a necessary evil. What then shall we say of magnetic impulses, varying with the varying strength of the battery, imparted to the bob of the pendulum?

And what shall we say of the contact? The merit of a good electrical contact is measured by the energy expended in pressure on its surfaces, and the whole of that energy in Bain's clock is directly robbed from the pendulum itself.

Of course, both these are crimes of the first magnitude.

But in those days the main object of the inventor was doubtless to make a clock which would go without being wound up, and it would appear to him and his friends to be a very creditable achievement. What surprises me is that these first-class "howlers" should have been repeated by inventors so often since, and are still being perpetrated in a more or less virulent form.

I think it is due to ignorance, and the tendency of the inventor to rush into print when he has something new.

It may surprise people to know that since Bain's application of 1840, there have been 800 published patents on the subject of electric clocks, without counting those which never got beyond the stage of provisional application.

Accustomed as I have been to look through them in batches from time to time, the prevailing impression I have gathered is that very few of these inventors have taken the trouble to ascertain first what other people have done in the same line. Of inventors generally, one must say that their education, if it ever comes to them at all, comes as a result of costly experience in attempting to make and sell their inventions.

Not more than ten per cent. of these inventions have ever been heard of again. We must assume that the difficulties of manufacturing and marketing have proved too great for the enthusiasm and ability of the inventor to overcome, or that their lack of originality and merit alone is sufficient to account for their oblivion.

Surely the Patent Libraries, with their excellent indices, the proceedings of the Scientific Societies, the Trade Journals, and the popular Science Weeklies, rob the inventor of all excuse for ignorance of his subject, through which he fails, in nine cases out of ten, to stand on the shoulders of those who have gone before him.

It is with a view of still further dispelling this ignorance and to encourage interest in the History of Electric Clock inventions that this book has been written.

CHAPTER II

ALEXANDER BAIN

The first inventor of electric clocks
His quarrel with Wheatstone

IN Chapter I, I mentioned Bain as the first inventor of electric clocks. His patent, No. 8783, of October, 1840, entitles him to that distinction, since he foresaw the various ways in which electricity could be used, and expressed them in terms which are wide enough to serve as the basis of our classification to-day.

And in no subject is classification more necessary. The careless use of the term "synchronised clocks" has contributed to the prevailing ignorance and muddle-headedness which it must be admitted with regret is shared by the watch and clock making profession.

When, therefore, we talk of electric clocks, let us make up our minds whether we mean—

(I) *Independent self-contained clocks*, whose motive power is electricity.

(II) *Synchronising systems*, in which a signal is transmitted at regular but infrequent intervals, such as hourly or daily, to correct the hands of independent clocks, whether they be electrically driven or key-wound, or

(III) *Circuits of electrical impulse dials*, in which a master clock transmits impulses every minute or half-minute to propel the hands.

It will be obvious that among the master clocks in class III there will be found many of class I, and that they all, whether key-wound or self-wound, will be capable of synchronisation by class II.

Alexander Bain came to London in 1837 "to seek employment as a journeyman clock maker," as he himself says. This was the year in which Cook and Wheatstone took out their first patent for the Electric Telegraph. Bain undoubtedly possessed intelligence and ability above his class and he had ideas on telegraphic printing and electric clocks.

He sought assistance and patronage, and was introduced to Wheatstone on August 1st, 1840. Wheatstone approved of him and his ideas, and invited him to complete some of his models and submit them. This he did on the 18th of that month. For £5 down and the promise of £50 on completion, Wheatstone bought so much of Bain's apparatus as related to printing telegraphs and from these fateful interviews, when electric clocks were discussed, arose a first-class inventors' quarrel.

Wheatstone had already considered the obvious applications of his telegraph to clocks, and he had discussed them with his friends. He read a paper before the Royal Society in November, 1840, exhibiting a clock in the Library. But Bain had already filed his first patent on the 10th October, and thereafter he was convinced that Wheatstone had absorbed his ideas.

When we recollect that the fact that electricity could be conducted along a wire and could be made to do work by electro-magnetism had only just dawned upon human intelligence, that knowledge or experience were lacking, and that the science was in a hazy and nebulous state, that not even the terms "series" and "parallel" had been coined, we can only consider this Patent as a remarkable achievement.

Fig. 1 represents Bain's first conception of an electric clock system. The pendulum is of seconds beat and is driven by an ordinary key-wound clock movement not shown. A little curved bracket on its left-hand side rubs backwards and forwards along the surface of some insulating material bisected with a band of metal. Thus

contact is made every second, and the electrical impulse is transmitted through a series of electrical impulse dials from a battery. The dial movement has a reciprocating armature picking up one tooth at a time differing only in details of design from the accepted practice

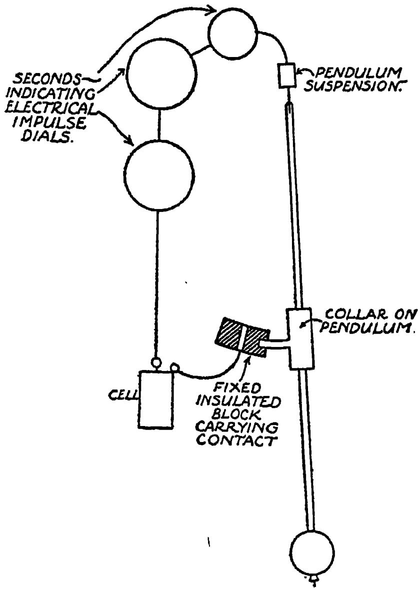


Fig. 1

to-day. Of course Bain's system was foredoomed to failure, but he at any rate clearly saw what was wanted and was the first to express it.

In May, 1842, Wheatstone exhibited his electric clock in the Library of the Royal Institution, Albemarle Street. A reference to this in the *Literary Gazette* roused Bain, who wrote an indignant letter to the editor, but alas! it was ungrammatical and ill-spelt, and was published with the fatal footnote:—

"Printed verbatim et literatim. *Fiat justicia, ruat coelum.*"

Wheatstone, then Professor of Science at King's College, demolished "this working mechanic formerly

in my employ"—a statement not strictly true—to his own satisfaction in the next issue. He would not admit having received any benefit from Bain or his ideas, and charged him with infringing his own patents. Wheatstone brought up his heavy guns, statements from Isambard Brunel and other eminent engineers, who testified that they had discussed electric clocks with him early in 1840, but he had taken out no patents

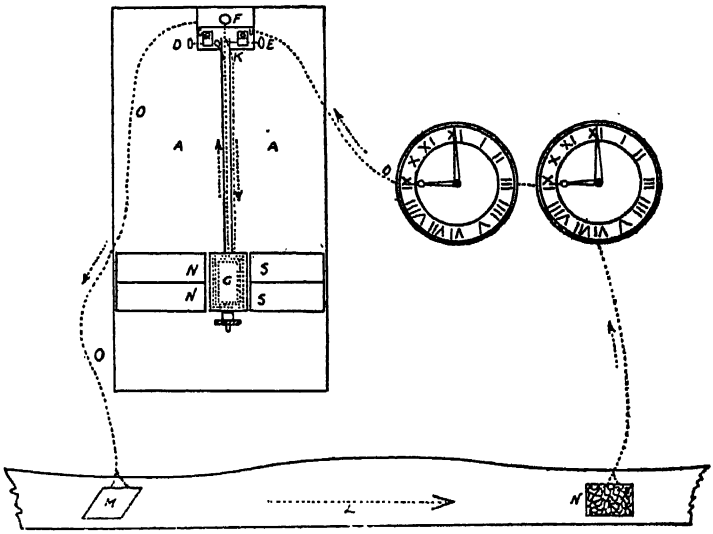


Fig. 2

specifically for electric clocks in those early years, and my sympathies in this case are with the journeyman clockmaker rather than with the Professor, who answered him with "The brutal *non possumus*, decorated with aristocratic wit." The employers' dice were more heavily loaded against the employees' in those days than they are now, and we have only to look at Bain's next patent to realise his originality and vision.

This was No. 9745 of 1843, an "omnibus" patent, from which we select a few drawings for reproduction.

His fig. 2 is an electro-magnetically driven pendulum,

its bob and coil swinging between permanent magnets and its contact made at the top of the pendulum by a toggle, a little ball on a stem, falling over right and left as it swings.

This will be recognised as the progenitor in the direct line of many clocks whose pendulums are electro-magnetically maintained, such as the Bulle, whose descent I will trace later on, and I think we would do well to encourage a little of the Japanese veneration of our ancestry.

Note the earth battery, which of course corresponded to the Leclanché cell of our day, M & N being the zinc and carbon and the moist earth the electrolyte.

Figs. 3 and 4 show a couple of electrical impulse dials in series with the pendulum and under the control of the little falling ball toggle contact, which was, of course, quite impossible as a switch for the transmission of really useful electrical impulses, but Bain could hardly be expected to know that in those early days.

Figs. 3* and 4* represent 3 and 4 in detail, the former being a polarized step by step electrical impulse dial movement, and the latter a polarized electro-magnetic release of a key-wound clock, both of which are equally ancestral, having been steadily developed and improved into forms in common use to-day.

The arrangement of the moving coil C between the poles of the permanent magnets B is a very efficient one and needs to be so in view of the small power available.

Fig. 5 is still more prophetic, as it forecasts the risk of a line disconnection in a large series circuit stopping a number of clocks and shows the series-parallel grouping which the Synchronome Company has recently introduced as common practice in modern electric time service.

Shortly afterwards, in 1845 and 1847 to be precise, Bain improved his contact and reversed the current at each swing, as shown in fig. 6, in which will be seen

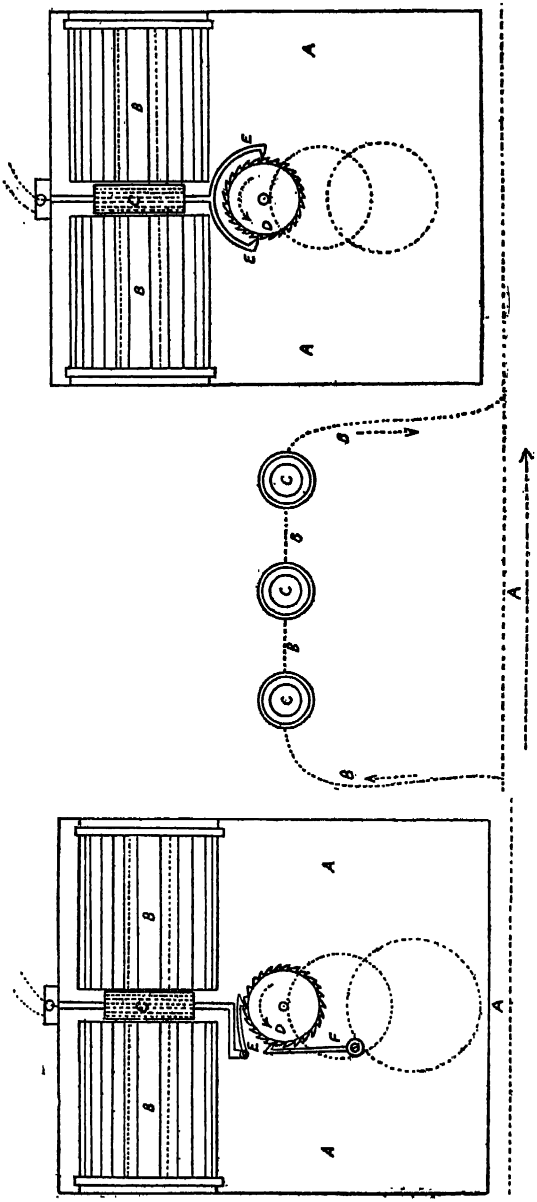


Fig. 3, Fig. 4, Fig. 5

his metal bridge or sliding bar pushed backwards and forwards by a pin on the pendulum over the faces of contact blocks which are half ivory and half gold.

It will be observed that an increased arc will result in a shorter duration of contact, and vice-versa, thus giving a weaker battery more time to pull.

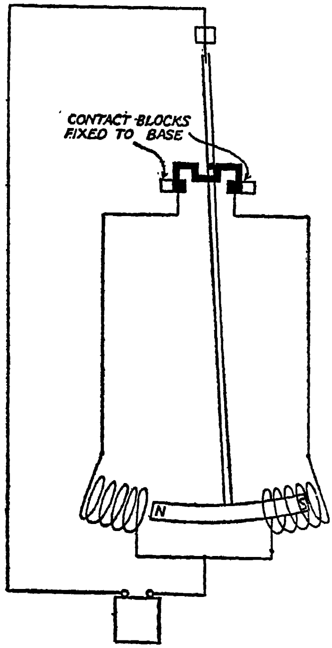


Fig. 6

I wish it were possible to say a pleasant word about Bain's work on leaving him at the end of this chapter. Some eulogy of him as a pioneer is no doubt expected, but it is high time that a critical judgment was passed upon his work—now nearly a century old—and truth compels the admission that his system was a failure, that not only his own clocks, but all those which sought to develop his methods were a cause of loss and disappointment and failed to survive the Victorian era.

They brought electric clocks into disrepute, and did much to arouse that deepseated prejudice which the writer has found it such a hard task to overcome.

Lord Grimthorpe, in "Clocks, Watches and Bells" says, "These clocks never answered in any practical sense; nor would anything but the strongest evidence, independent of the inventor, convince me that any independent pendulum directly maintained by electricity can succeed in keeping good time for any considerable period."

But we can now be more precise regarding the actual causes of failure, which are those referred to in the introduction.

Two fundamental principles were flagrantly violated; the whole of the energy for the purpose of making electrical contact was robbed from the pendulum, and, apart from that serious interference with the natural period of its vibrations, the impulses themselves were a grave cause of disturbance and their value varied with the variations of current.

It is easy for us to see that nothing substantial could be built on such foundations, yet even fifty years of failure were insufficient to teach these obvious truths, and the errors still persist.

CHAPTER III

SIR CHARLES WHEATSTONE

The "Magneta" Induction System

WE turn our attention to Wheatstone, a name to conjure with among those who laid the foundations of the electrical engineering profession. It is nearly a hundred years ago since the invention of the electric telegraph, and we shall shortly be celebrating its centenary, no doubt with the same enthusiasm which marked the recent railway centenary celebrations. When we think of the dawn of telegraphy we do not forget Froment in France, Steinheil in Germany, and Morse in America, but we rightly associate the first practical electrical telegraph with Wheatstone.

He was born in 1802, and was appointed Professor of Physics at King's College in 1834, where he laid down half-a-mile of wire in the vaults to discover the time taken to transmit an electrical impulse along a line. His estimate of 250,000 miles per second as the speed of electricity was a good shot. He took out his first telegraph patent in 1837, and in the same year was elected a Fellow of the Royal Society, to whom he communicated his first paper on electric clocks in 1840. He was knighted in 1868, and died in 1875, having bequeathed to the working electrician for all time one of his most useful tools—the Wheatstone Bridge.

The MS. of his 1840 paper on electric clocks is still on file at the Royal Society, but the illustrations of the model he exhibited in the Library are missing. Taking an ordinary key-wound clock, he mounted alongside its 'scape wheel a brass wheel, shown in fig. 7, with sixty slots cut in its periphery, filled with wooden segments, and provided a spring to make contact with it—a

primaeval commutator, destined in a later age for the dynamo, the motor and the magneto, but impossible in a clock on account of its friction. He applied "a constant voltaic battery of a few elements," and the resulting impulses were transmitted to electrical dial movements operating every second.

This system soon disappeared, or, perhaps, never really saw the light. Neither transmitter nor receiver was good enough, and the current supply must have been precarious in those pre-Leclanché days.

He also described in this 1840 Royal Society Paper "another kind of electric clock in which Faraday's Magneto-electric currents are employed." He takes an ordinary key-wound clock, but uses a magnetised cylindrical steel bar as a pendulum bob vibrating within a coil. Its motion in a magnetic field induced a current transmitted to dials containing very light metal discs maintained in constant rotation, thereby moving the hands continuously.

The history of electric clocks and the whole story of their development constantly reveals a truth which should have been obvious to all inventors, yet which you will hardly ever find expressed in words—the simple fact that the pendulum and the wheelwork which drives it should, as far as possible, be left alone to perform its true function of measuring time and should not be interfered with by contacts or be called upon to do work of any kind.

It has been my custom, the habit of a life-time, to apply this acid test to electric clock inventions, thus to discriminate between good and bad, to explain the disappearance of past systems and to estimate the success or failure of new ones, according to the extent to which the clock is robbed of its power for contact-making purposes.

Perhaps it is as well that such egregious examples come before us at this early stage in our review. "Better a little chiding than a big heartache," better a little plain

language now, than more polite but perhaps tiresome reiteration. Consider fig. 7, a commutator carried upon a 'scape wheel arbor. If the spring is strong enough to make a good contact, it spoils the time-keeping or stops the clock; if we weaken it, we make a bad contact. We are between the devil and the deep sea, the whole of the energy being stolen from the clock.

And what shall we say of the use of the pendulum itself as a magneto-electric generator? What sort of time-keeping would you expect from a clock over-

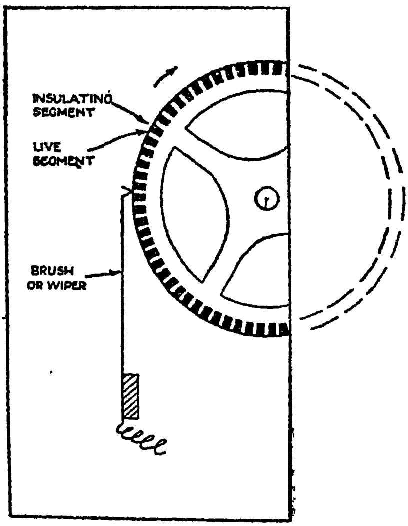


Fig. 7

driven by a heavy weight, so that its pendulum bob may swing through a bath of treacle or a strong magnetic field? And how could you expect the faint resultant impulses to be of any real use for driving clock hands?

We cannot doubt Wheatstone's knowledge of Galileo and Huyghens. He must have known something of the mathematics of the pendulum and of the achievements of Tompion, Harrison, Mudge, and Arnold in the century immediately preceding his own. Such

ruthless interference with the freedom of the pendulum to swing under the uninterrupted influence of gravity was enough to make them turn in their graves!

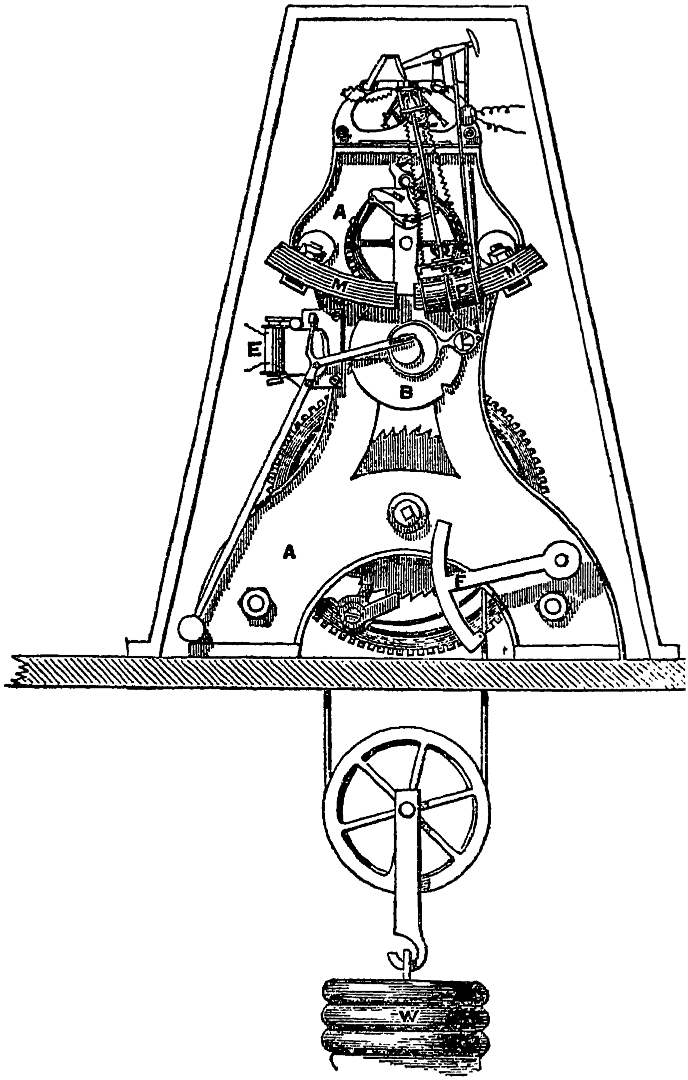


Fig. 8

Yet late in life Wheatstone made a serious effort to introduce this system through his firm, the British Telegraph Manufacturing Company, at 172 Great Portland Street, W., and I reproduce fig. 8 from the descriptive leaflet they issued.

It will be seen that the bob of the short pendulum P is a coil embracing fixed permanent magnets M.M. over which it is forced backwards and forwards by exceptionally powerful clockwork.

They were installed in the London University and in the Royal Institution, where the master clock is still preserved. That installation was started in 1873, but was abandoned soon after the death of its inventor, in 1875. The late Mr. Augustus Stroh told me that when he was with Wheatstone a dozen similar master clocks were made by Gillett & Bland, of Croydon.

I have only found four; the others *may* have been erected, but it is certain that the installations were soon abandoned.

But Wheatstone's reputation rests securely on other foundations. He taught us the alphabet of electrical engineering almost before it existed. He was the first to appreciate Ohm's law, $I=E/R$, $E=IR$, $R=E/I$, without which every electrician is blind and impotent.

And ultimately the principles underlying his magneto-electric system of clocks were applied in a radically different manner by Martin Fischer, of Zurich, in 1900, who produced a system known throughout the world as the "Magneta."

Fischer made two fundamental improvements: (1) his magneto-electric generator was driven by a separate train of wheelwork, let off by the going train of a key-wound clock which was otherwise uninterfered with; and (2) he generated his impulses once a minute instead of every second.

The arrangement is illustrated in fig. 9, a horizontal section through the master clock. The releasing lever 5 forms the connection between the two trains of wheel-

work, the power train on the left and the going train on the right. When the latter releases the lever at the end of a minute, the crank 6 is free to make one revolu-

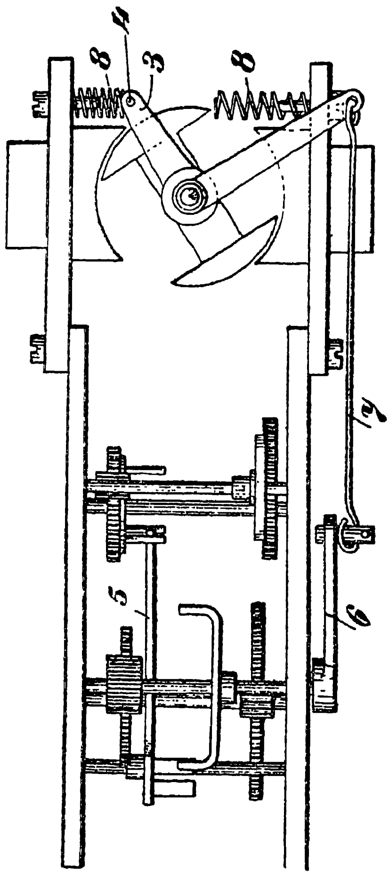


Fig. 9

tion, and by means of the connecting rod 7 it gives the armature a rapid to-and-fro vibration, banked by the springs 8, which not only reduce shock, but conserve some of the energy which would otherwise be lost in starting and stopping. The dial movements are, of

course, of a polarised type, and are designed for quick action, leaving a spring to do the work of moving the hands. The inductor is highly efficient, the magnetic field being completely enclosed in iron. It works at a much higher speed than Wheatstone's, and the space available for the motion of the armature is unlimited. The duration of the impulses varies from 0·1 to 0·2 second, according to self-induction, etc.

When one has to take hold of small amounts of mechanical energy, isolated in point of time, and convert them into electrical energy, one is bound to lose most of it. Wheatstone dealt with a very small quantity every second, whereas Fischer deals with a much larger amount every minute, and consequently the loss is greatly reduced, though still considerable. The limitations of such a system are obvious, and a master clock capable of operating a large circuit of small dials, or even a small circuit of large dials, must be costly and cumbersome compared with one which has only to operate a switch.

If a given dial requires 6 ft.-lbs. of energy per week to operate it, then (assuming an efficiency of 100 per cent.) 50 dials will require 300 ft.-lbs. to be stored in the master clock weekly, in addition to its own going power; but, as we have said, in the conversion of small mechanical energy into electricity and its reconversion into ft.-lbs. an efficiency of, say, 25 per cent. is the most we can hope to get, and, consequently, 1,200 ft.-lbs. will be required per week for 50 dials. In practice, daily winding is usually resorted to, and, though this reduces the necessary power storage to one-seventh, the size and cost of the master clock is still a difficulty in the case of large circuits, whilst the capacity of each master clock is limited, and, when a time-circuit requires further extension, an additional inductor is usually installed.

The arguments in favour of an induction system were so well stated by Wheatstone in the rare pamphlet

from which fig. 9 is reproduced that I cannot do better than give some extracts from it, taking care to use inverted commas lest you should think I was quoting from the latest printed matter of the Magneta Time Co., Ltd.

"Various systems of electric clocks have been suggested and tried; but they have all practically failed, principally by reason of the oxidation of the contacts at those points where the circuit is periodically interrupted."

"The system of magneto-electric clocks has been designed so as to be effectually free from this objection. The maintaining power is supplied by magneto-electric currents developed in a coil of wire which is made to oscillate over the poles of permanent magnets. . . . In this way the whole wire circuit remains unbroken, and the currents are alternately inverted without any making and remaking of contacts (which are the chief source of failure of the electric system) being employed."

"A single motor, on this principle, will actuate sixty or seventy indicating clocks in the same circuit."

It cannot be too clearly emphasised that in the Magneta system the inductor is operated by a train of wheel-work quite distinct from the going train which only has to release it, and consequently there is little, if any, interference with the time-keeping properties of the high-class Graham dead-beat escapement used.

CHAPTER IV

SYNCHRONISATION

Sympathetic Pendulums
Forcible Correction of the Hands

NOTHING having come of Bain and Wheatstone's inventions in the twenty years during which telegraphy was jumping to its job (1837/1857), Mr. R. L. Jones, the station master of Chester, evolved the idea of sympathetic pendulums by simply applying Bain's electro-magnetic pendulum bob (see fig. 2, chapter II) to existing key-wound clocks. His Patent, No. 702, of 1857, claims the obvious advantages of perfect synchronisation, of independent life in case of electrical failure, and small current consumption.

He applied it with success to his own turret clock at Chester and to a turret clock in the Victoria Tower in Liverpool. Then Mr. F. James Ritchie, of Edinburgh, took hold of it and supplied many observatories with pairs and triplets of sympathetic pendulums. In 1873, Ritchie carried it a step further. Realising what a very small expenditure of electrical energy was required to keep two tuned pendulums in phase, he was tempted to dispense with the spring or weight-driven maintenance with its merit of independent life, and drove the hands from the pendulum as Bain had done in his earliest earth-driven clocks, but by an improved method which may be described as a reversed gravity escapement.

Ritchie read papers before the Royal Scottish Society of Arts in 1861, 1873, and the Royal Society of Arts, London, in 1878. Fig. 10 is taken from the latter. Given a Bain pendulum whose vibrations are maintained by seconds contacts applied to a master pendulum (self-wound or key-wound), of the same length, then the

gravity levers A B are lifted by each semi-vibration, and on their fall they propel the motion work and the hands by the pallets *a*, *b*, locking the 'scape wheel by the stops a^2, b^2.

It is necessary that the pendulums which are to be controlled or impelled be regulated in the first place to

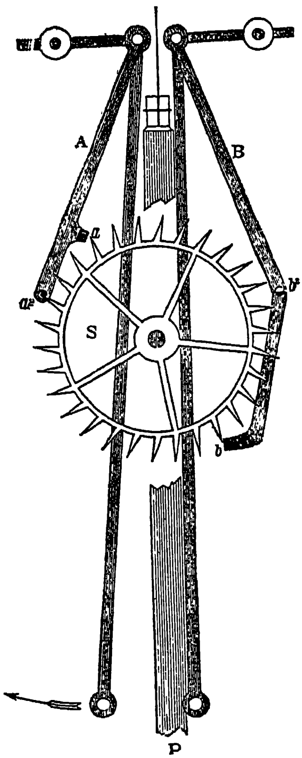


Fig. 10. Ritchie's Reversed Gravity Escapement

a fair degree of accuracy, as, of course, the more they are out of sympathy the more will the electro-magnet be required to interfere with the free action of gravity; and, if badly out of regulation, a temporary cessation of the seconds synchronising currents would allow a

pendulum to get so far out of phase that, when re-established, the electrical impulses would directly oppose its swing and bring it to a standstill.

This system had an exceptionally good trial. It was no small advantage to have the championship of a good old firm like James Ritchie & Sons, of Edinburgh, behind it for twenty years. It was installed in several important buildings, and it had other influential support. Mr. Ellis, who was in charge of the Time Department at Greenwich Observatory from 1855 to 1874, thought very well of it, and told me (in the discussion on my Institution of Electrical Engineers' Paper of 1899), that I over-estimated the nicety of regulation necessary to enable the current impulses to keep them in phase.

Nevertheless, sympathetic pendulums, either with or without maintenance, have not come into general use, the reasons for which I shall attempt to give in a later chapter.

Ritchie, their principal champion, seems to have been lacking in enthusiasm, conviction and continuity of purpose and wandered off into two other methods of synchronisation of ordinary clocks—the method of forcible electro-magnetic correction of the minute hands, and the method of a checked gaining rate.

In this I propose to follow him now, leaving for the next chapter the most interesting method of synchronisation, that which achieves automatic regulation of a pendulum by altering its effective length in accord with the error of the clock.

From Alexander Bain's pamphlet of 1843, "On the Application of the Electric Fluid to the Useful Arts," I reproduce fig. 11. The minute hand carries a pin behind it. The V-piece is on an armature of an electro-magnet fixed behind the fig. XII, not shown. The V is normally in the lower position as shown in dotted lines. When the synchronising signal arrives, the hand, which is as usual, spring-tight on its arbor, will be caught and zeroised by the V as the magnet lifts it.

Ritchie revived this method in 1876, but renounced it in favour of giving the clocks to be synchronised a permanent gaining rate and stopping their hands or their 'scape wheels by armatures interposed fifteen seconds before the hour and liberated exactly at the hour. In the meantime, however, Lund was patenting a variety of devices for correcting the hands, and his

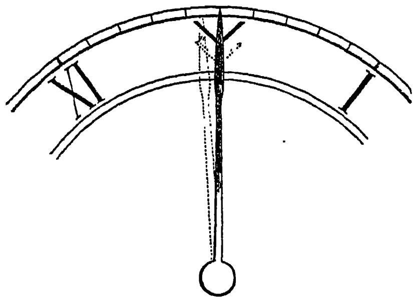


Fig. 11. Forcible Electro-Magnetic Correction

name will always be associated with the electro-magnetic clip, which, in response to an impulse transmitted every hour, grips the minute hands of a number of clocks, pulling them forward if slow and backward if fast. An exhaustive paper on this subject was read by him before the Society of Telegraph Engineers in 1881, from which fig. 12 is taken. It will be understood that the two cranked levers shown in dotted lines behind the dial are operated by the armature of an electro-magnet.

This system was successfully established in London in 1874, by the Standard Time Company, Ltd. Their central station at 19 and 21, Queen Victoria Street, E.C., is equipped with two steel and mercury regulators of the highest quality, which are kept very close to time by daily comparison with a special Greenwich time signal. Both these regulators make a contact of two seconds duration every hour, but only one of them takes the load, the other being held in reserve, and automatically switched in by a sentinel clock in the event of the

working regulator stopping. The hourly contacts operate relays, which send out impulses in all directions over London, correcting a large number of clocks, deflecting galvanometer needles or ringing single-stroke bells.

Subsequently they reverted to the V-shaped form applied nearer to the centre, as shown in fig. 13, which is self-explanatory.

If it were not for this service we should have nothing but the Greenwich time signals supplied to a few of the leading clockmakers and disseminated to the principal provincial post offices over the telegraph lines from St. Martin's-le-Grand at 10 a.m. or 1 p.m.

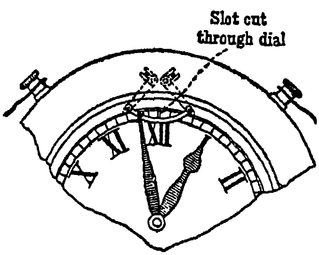


Fig. 12.
Lund's Electro-Magnetic Clip

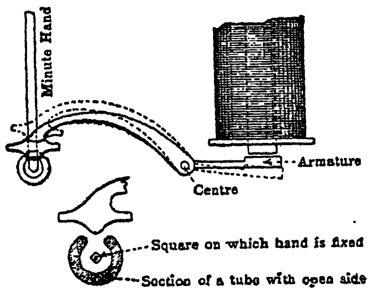


Fig. 13.
Standard Time Company's System

We ought to recognise the obligation we have been under to this, the only system of public time distribution in London.

It is safe to say that those who inaugurated this public service and their successors who have patiently carried it on for fifty years have never reaped an adequate reward but are more likely to do so now that the community has acquired a new clock consciousness thanks to the B.B.C. having brought Big Ben and the Greenwich six dot seconds into every home.

A somewhat similar arrangement is adopted by the Self-Winding Clock Company of New York, an installation of which is still in use on the Underground

Railways of London, controlled from a master clock at Lots Road Generating Station.

In the United States of America, thanks to the fact that their network of telegraph lines is not in the hands of the Government, the self-wound clocks of this company are spread over the whole country and are mostly synchronised by the Western Union Telegraph Co.

The self-wound clocks of the Hamilton-Sangamo Co. are provided with subsidiary rotary motors which correct the hands by Breguet's method described in the next chapter but do not regulate them.

A few years before the war the Normal-zeit Gesellschaft, *i.e.*, the Standard Time Company, of Berlin, attempted to establish a rival service in London, and registered a small Limited Company for the purpose under the very British name of the Greenwich Time Co., Ltd. They equipped a central time station at 106 Albany Street, N.W., with the reporting-back system of Puttkammer. Their method of checking the gaining rate was excellent, and consisted simply of a one-sided crutch which left the pendulum to swing idly for a period determined by the signal. The war put an end to their activities in this country.

I have said that Ritchie renounced forcible correction of the minute hand in favour of the checked gaining rate. I take fig. 14 from his 1875 Society of Arts Paper. The electro-magnet A receives a synchronising current of 15 seconds duration, terminating precisely at the hour. The disc M is behind the minute hand and fixed to it. When the clock arrives at the 45th second of the 59th minute, the lever B E D, centred at C, will stop the 'scape wheel by means of the pin in the end of D, thus holding up the clock until the cessation of the current, when the lever falls away.

It will be observed that, in effect, the clock stops itself, as is also the case in Messrs. Gent & Co.'s "Waiting Train" movement. The latter is really a synchroniser,

but I am not going to deal with it now; nor shall I deal here with the method of holding the Synchronome Free Pendulum in synchronisation with its slave clock, as both these inventions, though they involve in the one

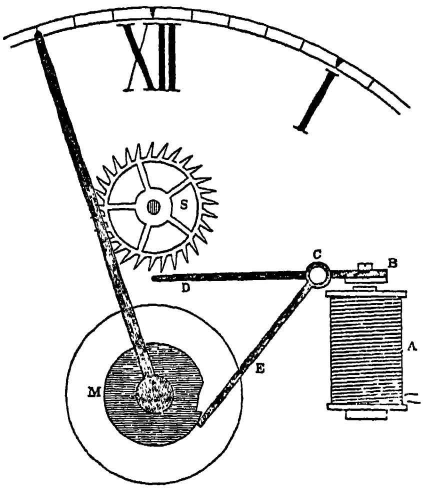


Fig. 14. Ritchie's Checked Gaining Rate System

case a checked gaining rate and in the other an acceleration of a losing rate, were intended for use with half-minute impulses and my classification in chapter II limits me to synchronising impulses at infrequent intervals, such as hourly or daily.

The checked gaining rate method survives in the Telegraph Department of H.M. Post Office. They have standardised it for the control of their "Hipp" driven master clocks.

CHAPTER V

SYNCHRONISATION (Contd.)

Breguet's Pendule Sympathique
Augustus Stroh

I HAVE reserved a couple of chapters for that class of synchroniser which seeks to alter the rate of a pendulum as a result of, and to the extent of, its past error; not because it is of any practical value or is the parent of any commercially successful system, but because it is a very pretty problem, full of intellectual and mechanical interest as an exercise and recreation. I promised to lead you up some pleasant by-paths, and this is one of them.

One does not expect the story of synchronisation to begin before the introduction of electricity, our idea of it being essentially based upon telegraphing a time signal, yet it actually commences in the year 1793, when Breguet, that incomparable mechanical genius, invented his *pendule sympathique*, which is illustrated in fig. 15.

These clocks are very rare and no two were made alike. Sir David Salomans tells us that H.M. the King possesses one which belonged to George III. The one illustrated was made in 1812. It is signed by one of Breguet's best men, Raby, and is said to have cost 25,000 francs.

There is a record that one was sold to the French Minister of Foreign Affairs. At the Court of King Louis XIV it was not customary to go to bed sober, but let us assume his Lordship capable of placing his watch in the receptacle prepared for it on the top of the clock. That is all he need do; he may leave the rest to its mother—*la mère horloge*.

During the night the watch will be nurtured and corrected by this model parent; it will be wound up and its hands set to time; more than that, if its rate is wrong, it will imbibe such synchronisation as it needs during the night, since its doting parent, with more

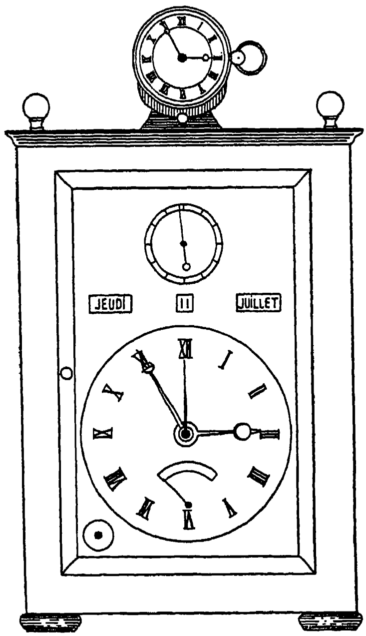


Fig. 15. Breguet's Pendule Sympathique.

than human ability, will measure precisely how far her child has strayed from the paths of virtue during the day and will alter its regulator accordingly, fast or slow, fitting it to take up again in the morning its daily task of influencing its owner to lead a more regular life.

We shall see how this is done by referring to fig. 16, for which I am indebted to Mr. Paul Chamberlain and to Mr. Rupert Gould for his reference to it.

In the watch is a separate train, like an alarm train, wound independently. Mounted on the cannon-pinion

is a pointed cam A, which, like a heart-shaped cam, is forced into the zero position by means of the lugs C, C^1 on the wheels B, B^1, when the synchronising signal received from the clock lets the setting-train off and the wheels B, B^1 make one revolution in the direction of

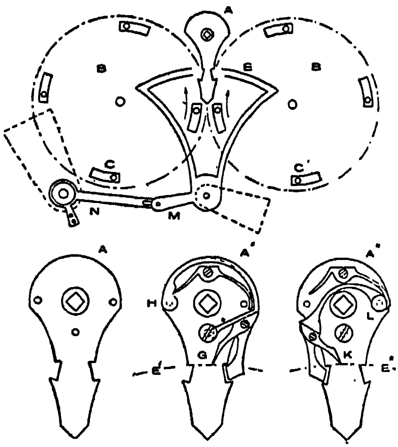


Fig. 16.—The Correcting Movement of Breguet's Pendule Sympathique.

the arrows. If the watch is fast, the cam, of course, is turned backwards. While so turning, one of the two clicks G, K, which it carries, engages with a serrated rack E, E^1, connected by intermediate levers M, N with the regulator of the watch. The regulator is thus moved towards "slow" an amount varying with the error of the watch at the moment when it was re-set.

Conversely, if the watch had been slow, the cam would have been turned onwards—and in so turning, the other click (pointing the other way) also carried by the cam, would have engaged with the serrated rack and moved the regulator towards "fast." The click not in action is swung out of the way about the pivots H, L, in a manner which need not be described. Owing to the connection between cam and regulator being by ratchets, and not by direct gearing, the regulator will take up,

within limits, any position with respect to the cam—it is not, for example, compelled to be at its mid-point when the cam is.

Breguet never wrote or published any account of his work, and this invention was probably unknown beyond his immediate circle. Not that this mattered

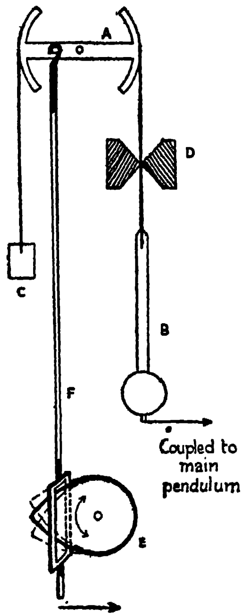


Fig. 17.—Stroh's Patented Synchroniser.

from any practical point of view, because it could serve no really useful purpose before the days of the electric telegraph.

In chapter III I referred to Wheatstone's master clocks as being hopeless time-keepers, since their pendulum bobs were called upon to act as magneto-electric generators. Now, Wheatstone had the advantage of the collaboration of a very clever mechanic in the production of his many inventions, Mr. Augustus Stroh, who in 1869 set himself the task of synchronising these master

clocks. He showed me a model of his synchroniser shortly before his decease at an advanced age in 1914. He made no mention of Breguet's synchroniser, and I don't think he was aware of it.

I take fig. 17 from his 1869 Patent No. 3208. A is a rocking beam carrying on the right a small subsidiary pendulum B, whose suspension spring passes between fixed jaws D. It is little more than a crutch, and is coupled to the main pendulum. Alternatively, Stroh used a collar weight supported by a silk cord; either the pendulum or the weight was counterbalanced by a weight C. Thus the effective length of the pendulum will be altered by rocking the beam A. This is accomplished by the rod F, or "feeler," and the cam E which is on the minute wheel. The synchronising signal pulls the feeler in the direction of the arrow, so that its vertical slot, shown in perspective, embraces the cam E, and F is pushed up or down according to the error of the latter, fast or slow. The operation of the feeler F by the synchronising magnet is not shown, but a very ingenious alternative combination of feeler, magnet and cam is shown in fig. 18 (Stroh's Patent, fig. 5).

The synchronising electro-magnet itself is pivoted and rotates with the clock. It is the cam E in another form. Its armature is pivoted to the feeler F, which now works vertically in guides. The armature lies loosely upon the poles of the magnet and will rock on either pole as a fulcrum, thus thrusting F up or down in accord with the angular error of E.

If the amount of the correction is exactly what is required, then the cam or magnet E, having started slow, will be the same amount slow when the next signal arrives, and no further movement of F will occur, but of course it would be practically impossible to make the correction exact.

Let us assume that the synchroniser is capable of correcting 50 per cent. of the error of rate at each operation, and let us call the correction constant $K=\frac{1}{2}$,

then the full correction will be made in a few successive operations, halving the error each time. If the correction constant is more than enough to do the job, say $K=1\frac{1}{2}$, there will be overshooting and rocking, and the rate

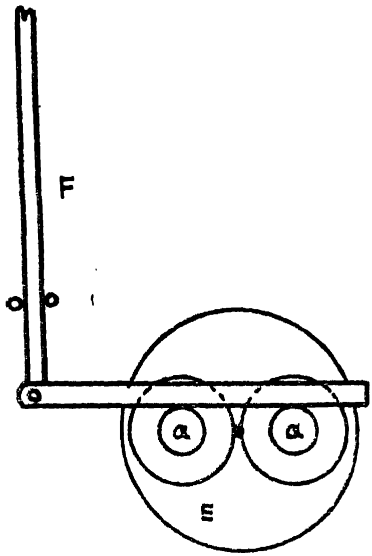


Fig. 18.—Stroh's System of Feeler, Magnet and Cam.

will take longer and longer to die out as K is nearer 2. But the correction constant must not amount to double the rate. If it does, it will oscillate to the full amount of the error, and if K were to exceed 2, the oscillations would increase in amplitude until they became infinite. It will be observed that only when the pendulum is of the original and proper length will the hands show correct time. Whenever there is any adjustment to be done as a result of rate, the hourly or daily synchronising impulse will correct the pendulum, but will leave the hands permanently fast or slow to the extent of the largest last corrected error.

Thus we see the superiority of Breguet's method.

He sets the hand to zero every time, consequently its angular position when the next synchronising signal comes through is a true measure of the error in its rate. The direction and extent of the corrective movement of the hand determines the direction and extent of the regulation.

CHAPTER VI

SYNCHRONISATION (Contd.)

R. J. Rudd

IN the last chapter, I described Breguet's method of synchronising and regulating a watch in 1793, and Stroh's regulation of a pendulum in 1869. Another synchroniser which obeys the same laws as that of Augustus Stroh was invented by R. J. Rudd, of Croydon,

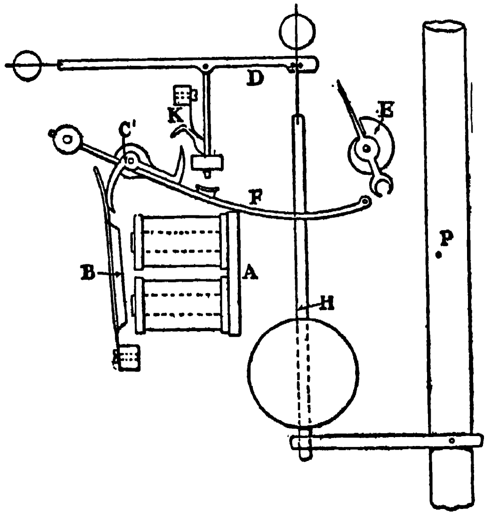


Fig. 19.

in 1898. The illustration of it (fig. 19) is taken from his Patent No. 19337 of that year.

In fig. 19, A is the synchronising magnet operating the armature B, which raises the feeler F through the medium of the Z-shaped lever C, which latter releases

the clutch K and allows the slide D on the pendulum suspension spring to fall and to be re-set into whatever position may be dictated by the cam E. The short

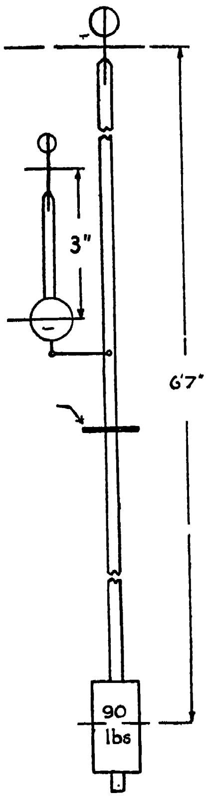


Fig. 20.

Rudd's Synchronisation of Wallis' Clock

The Tray indicated by arrow is in the middle of the pendulum and a temporary weight of about 6 or 7 lbs. is held available to drop on to it as a substitute for the subsidiary pendulum if the latter is disconnected.

A movement of ¼in. of the synchronising slide produces a difference of 10-15 seconds per day.

pendulum H is a subsidiary one linked to the main pendulum.

Rudd applied this invention to the handsome public bracket clock of Thomas Wallis & Co., Ltd., Holborn Circus, using the hourly synchronising service of the Standard Time Co., Ltd. Fig. 20 is a reproduction of its details, taken from a page in my note book in 1910.

It will be observed that the pendulum beats 1½ seconds and has a bob of about 90 lbs. The object of

the subsidiary pendulum is to "dilute" the synchroniser, which it does very effectively. A considerable movement of the slide embracing the suspension spring is required to produce a small alteration in the rate, and the result is approximately ¼ in. for 10 or 15 seconds per day.

It will be observed that the regulator is set afresh by each signal, so that there can be no cumulative action and no "rocking" except when the value of the correction is greater than is needed, in which case there will be a few diminishing oscillations. If a seconds hand was provided, its position would not be corrected automatically; the clock having settled down to the closest performance it is capable of, one would then set the hand to zero. If afterwards you deliberately upset the rate of the pendulum, the synchroniser would correct it, the cam and the hand finding a new zero position, and the error of the latter would indicate the amount of the correction effected.

So far as I am aware, this is the only rate-correcting synchroniser which has ever been given a real job to do. It did it well, but I have not heard that it has been asked to do another.

Is not this a striking example of the inability of the average inventor to gauge the practical value of his creations? Though clever and effective, it was never really wanted, and never earned its patent fee even in the age of telegraphed time signals, and certainly will not do so now.

Yet it has a little niche of its own in the history of horology, because, by means of it, its inventor achieved the first free pendulum. But that is another story, which will be dealt with in its proper place.

Unfortunately, none of these inventors, neither Breguet, Stroh, nor Rudd, explained what they were doing or why they adopted their particular methods. It has been left to me to ascertain and explain the underlying principles, and, whilst that has been a pleasant

task, one cannot but regret the want of that publicity which would have discovered them in their own general tion and would have given us an instructive chapter on these principles in our horological text-books.

I have often referred to the way in which patentees rush into print without any effort to ascertain whether their inventions are original. The patent files are stuffed with rubbish, old and new. What is good is usually old, and what is new won't work. Inventors are prone to vanity, and pride goeth before a fall.

It seems hardly conceivable that though this problem of synchronisation by correction of rate was solved in 1793, 1869, and 1898, other synchronising systems which do not synchronise at all but only rock the error have been "invented" and solemnly patented by others over and over again.

Though the patent law has been revised and so greatly improved that the officials try to protect the tyro from himself by quoting anticipations, it is still no part of their duty to point out underlying fallacies.

A fool and his money are soon parted, and it is not for us to complain of this method of helping to pay off the National Debt.

I reproduce from a contribution to the discussion of my Institution of Electrical Engineers' Paper of 1910, an illustration of one of these fallacious synchronisers in fig. 21. At first sight it appears to be, in principle, identical with Stroh, but the feeler F in this case raises or lowers a collar weight on the pendulum H by means of a winch A, the direction and amount of whose movement is dependent upon the position of the pointer E.

A little reflection will show that the pointer E may be indicating correct time when the signal arrives, but the rate may, and probably will, require correction, which it will not get.

On the other hand, the rate may be correct when the signal comes along, but the dial will almost certainly

be wrong (as a result of the previous perverse action of the synchroniser), and the perfect rating will be upset.

It cannot synchronise at all, but will only "rock" the

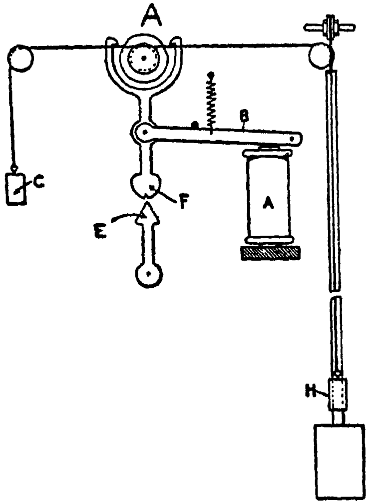


Fig. 21.

error backwards and forwards, fast and slow. The wave-lengths of the oscillations are, of course, dependent upon the amount of correction effected by the synchroniser at each hour, but the amplitude of the waves will never diminish. The mistake is due to the confusion of two different things, the rate of the clock and its indicated error, *i.e.*, the divergence of the hand from true time. This system attempts to synchronise from the latter by repeated alterations of the rate proportionate to the extent of the error; but, these alterations being cumulative, an error of equal value is piled up in the opposite sign. In fig. 22 the initial error is taken as being +2 per hour (whether seconds or minutes is of no consequence), and it is assumed that an error in the

pointer of that angular dimension will enable the synchronising feeler to lower the weight on the pendulum one-half of the amount necessary to correct that error.

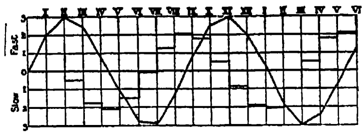


Fig. 22.

The rate appears in steps as altered hour by hour by the synchronising signal. The thicker line shows the divergence of the hand from true time, or, in other words, the indicated error.

If R is the rate and K the correction constant, then approximately $\frac{R}{\sqrt{K}}$ = amplitude of the vibration and $\frac{2\pi}{\sqrt{K}}$ = period of vibration. Thus in the above curve the amplitude is 2·828 and the period 8.9 hours, and, if we make $K = \frac{1}{4}$, the amplitude is 4·0 and the period is 12·56 hours. If the correction is exact ($K = 1$), the amplitude is 2 and the period 6.28 hours. If, therefore, the synchronising line broke down, the interruption would be just as likely to occur when the rate was at its maximum, minus or plus, as when near zero.

It is more kindly not to mention the authors of these blunders by name, but I quote the patent numbers of some other typical ones for the benefit of the serious student, viz., No. 2425 of 1905 and No. 9287 of 1911.

We have learnt from Breguet that the ideal synchroniser is one which both corrects the rate and sets the hands. There is no difficulty in doing this by electromagnetic means as he did mechanically. It simplifies the problem greatly, because if you zeroise the hands at each hour, the indicated error becomes the rate. Take, for instance, the cam A of fig. 23 and divide it into two insulated halves as a commutator with two

segments—AA_1—connected respectively with a raising or accelerating magnet B, and a lowering or slowing magnet B_1. The synchronising lever is a conductor

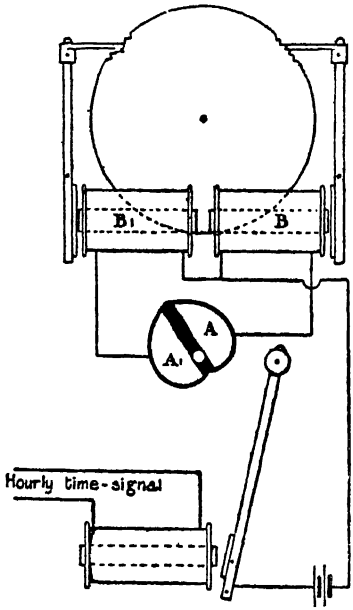


Fig. 23.

from battery, and, if it habitually finds the cam slow, it will operate the raising magnet, which will wind up the capstan by means of an ordinary electrical impulse dial movement, whereas, if it finds the cam fast, it will lower it. There is little use in making the correction proportionate to the error; it will soon find zero and keep it. Give it a small correction constant and let it work off the rate at its leisure.

Assuming, of course, that it is worth doing, which I doubt; it could only interest the proprietors of a wiring net-work and the providers of a public service, as they alone could make any extensive use of it. There is but

one such company in England, and, as they have not thought it worth while, I recommend inventors to turn their attention to more remunerative channels, and then to ask themselves two elementary questions—is it original? and is it wanted?

CHAPTER VII

HALF-MINUTE RELEASE AND CONTROL

THE last two chapters dealt only with the applications of time signals spaced at wide intervals such as hourly or daily. Synchronisation of that kind was the natural product of *The Electric Telegraph* of nearly 100 years ago. They knew what they wanted then, as we do now—uniformity and accuracy of time-keeping—but the synchronous propulsion of pendulums by seconds impulses by Bain, Wheatstone and Jones having failed, and such Continental systems of minute impulses as had been tried here also having failed, it would appear that they did not dare to ask for more than an occasional influence from this new "will-o'-the-wisp."

Confidence in the reliability of electric signals and what they could do was a plant of slow growth. Systems of electrically propelled dials progressing by half-minute steps did not come into general use until 1895, when the Synchronome invention proved that it was possible to transmit 1,051,200 electrical impulses per annum of identical wave-shape.

When electrical time service had thus been established as a reputable branch of the electrical engineering profession and circuits of electrically propelled dials of half-minute periodicity were coming into popular use, synchronisation developed in another direction.

The *synchronous propulsion* of dials in half-minute steps is, after all, only synchronisation plus the going power or push. To realise this, let us consider how many clocks one meets with which are already provided with their own going power and how easily half-minute impulses can be applied to them.

Being provided with a power train of wheelwork with energy stored in a spring or a weight, they can be relieved of their pendulums and escapements and be permitted to run for half-minute's space, under the dictates of a half minute electrical impulse, or they may retain their pendulums which would be synchronised every half-minute. In either case the existing works are retained and the clocks will continue to be wound up as before.

We saw the earliest example of releasing in Bain's patent of 1843, Chapter II, fig. 4, and we shall see the latest example of synchronising in the hit-and-miss method as used in the free pendulum in Chapter XXVII.

To release a clock of any kind, all one has to do is to remove its escapement and pendulum and substitute an electro-magnet and armature, which will let the wheel-work run forward half-a-minute's space. The wheel to which the armature is applied must of course revolve once per half-minute, or in a period exactly divisible by half-minutes.

A small striking bracket or mantel-shelf clock which it is desired to include in a circuit of electrical impulse dials without losing the feature of the strike, can be dealt with in the most convenient and practical way by fitting it with an electro-magnetic release. Perfect synchronism and the retention of the strike is thus obtained at the cost of weekly winding, which is rarely objected to.

Fully automatic electrical striking gear will always remain a delightful pastime for the ingenious amateur mechanic. Space will not admit a chapter on that subject, suffice it to say that whilst the use of electricity for time measurement and time indication is distinguished by great simplicity, economy and efficiency, it has no such advantages to contribute to chiming or striking which is a mechanical problem and has been solved as such. The processes of starting, stroke counting and

stroke spacing can be performed electrically, instead of mechanically, but cannot be dispensed with.

Only in the case of heavy bells, where costly mechanical turret clock works can be saved, does it become worth while, since the rotary motor which provides the power for pulling the hammers, also spaces the strokes. On the other hand, domestic striking clocks abound, and no economy results from substituting their works.

Many a large institution or famous firm of manufacturers is possessed of an old turret clock whose reputation as a time-keeper it were kinder not to discuss. If it does not strike the hours, then, when the modern and inevitable service of uniform and accurate time is "laid on" by means of a circuit of half-minute electrical impulse dials, the heavy turret clock movement is scrapped in favour of the "one-wheel" step-by-step movement mechanism described in Chapter XVI, the clock chamber being swept and garnished.

But if the old turret clock strikes the hours and perhaps chimes the quarters as well, and it is desired to retain these features, then it can be given a new lease of life by relieving it of its pendulum and "escaping" its wheel-work half a minute at a time. Good design and construction are essential, and it is well, in the case of a Grimthorpe Gravity Escapement to retain the fan in order to mitigate the shocks and prevent tripping.

There is much to be said in favour of dealing with employees' time recorders in the same way. Such machines are usually substantial and well-made and contain powerful clock works with two mainsprings competent to drive the type printing wheels and inking ribbons with automatic motions for effecting "day," "in and out," colour, and other changes.

These machines, being made in quantity as independent units, are accepted when met with in an electric time-circuit and left intact except for the sub-

stitution of an electro-magnetic release for their pendulums and escapements. Wherever type-printing wheels are concerned, *minute* periodicity in clean jumps from one figure to the next is obviously desirable. This is easily derived from a *half-minute* time-circuit by submerging every other impulse in the release mechanism, or in a "minute-impulse" relay.

Alternatively, Time Recorder Clocks may be given a losing rate and their pendulums provided with a spring which will engage with a "half-minute obstruction" of the "Reflex" type introduced by Messrs. Gent and described in Chapter XXVII.

All these devices are ephemeral, being but a temporary concession to the inertia of established patterns of key-wound clocks. They are a feature of the transition period between the old and the new, between mechanical and electrical, between individualism and collectivism.

Direct electrical propulsion is ultimately inevitable, and, indeed, has already been adopted by the Synchronome Co. to control most types of time recorders in Great Britain. It is also used in the time stamps of the Stromberg Electric Company of Chicago, U.S.A.

The feature of all releases is that the power train remains stopped for half a minute, and each half-minute impulse lets it run that amount.

In another form of synchronisation, which was intended for occasional impulses, but which has since been used for short period working, the clock is given a gaining rate and disengages its pendulum from the wheel-work, which ceases to progress until the impulse restores the connection between them.

In Chapter IV, Ritchie's gaining rate synchroniser was illustrated in fig. 14, and it was, I believe, the first operated in this way. A disc on the minute hand arbor has a step cut in it which allows a lever to thrust a pin into the 'scape-wheel teeth, thus stopping the wheel-work of the clock when it reaches zero hour, but leaving the pendulum swinging so that the clock will start

again when the time signal arrives and removes the obstruction.

In 1907 Messrs. Gent & Co., of Leicester, developed the same idea for the control of a Hipp driven pendulum by half-minute impulses. Fig. 24 is taken from their Patent No. 20878 of that year, in which it will be seen that the pin F2 on the wheel F raises a lever K,K1 which

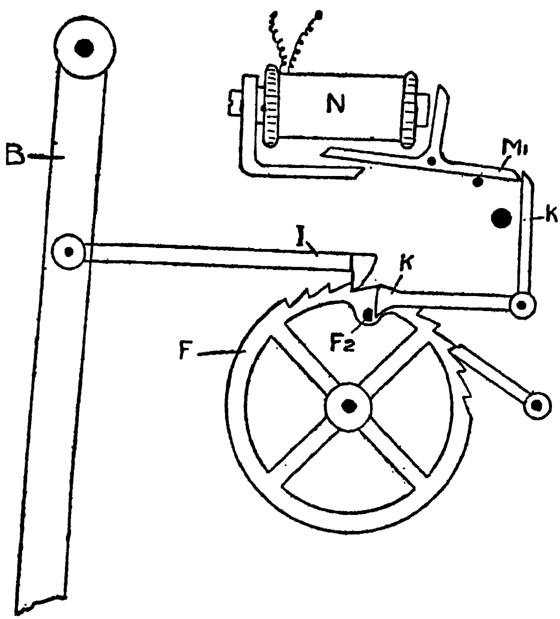


Fig. 24. Gent's Waiting Train

effectually masks the teeth and prevents further gathering by the pendulum until it is released by the half-minute impulse received by the magnet N. This ingenious device is known as the "Waiting Train" movement, and has been largely used for turret clocks in conjunction with the Hipp pendulum, which is ideal as a source of power for such purposes.

But the story of motor control by half-minute

impulses begins with my chaser switch, illustrated in fig. 25, taken from Patent No. 1587 of 1895. The arm A, concentric with an electrical impulse dial movement of half-minute periodicity, is normally held against stop B by a helical spring C and against the contact pillar D on the large wheel E. This latter completes the circuit of a power supply through the rotary motor M with the

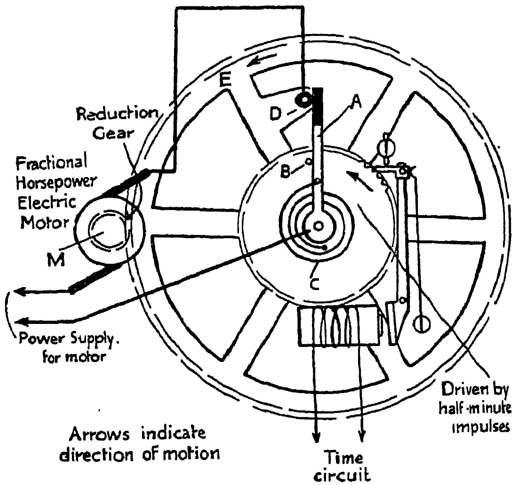


Fig. 25.

result that if the large wheel E gains on the dial movement, a break will occur at D, and A will continually chase it. If the power supply is cut off, then the dial movement stores its half-minutes in spring C and the rotary motor will have an uninterrupted run until it has restored the turret clock hands to true time.

Fig. 26 shows the substitution of a rheostat for the contact pillar D. The analogy between this and the control of the pendulum motor in fig. 24 will be obvious, the masking of the gathering pawl being the mechanical equivalent of the switching off at D.

Mr. A. G. Jackson, of Brisbane, has, since the beginning of this century, preferred a fixed switch instead

of a rotating one, and his method, which is to be seen in many turret clocks in Australia, is illustrated in fig. 27. The arm is on a half-minute wheel of the motor train and snaps the switch D which is restored by the overrun, but in the meantime the motor circuit has been

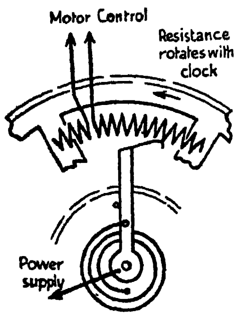


Fig. 26.

broken at B and will in due course be restored by the next half-minute impulse.

The Gerrish method of driving telescopes as used at Harvard, Greenwich and other observatories, is

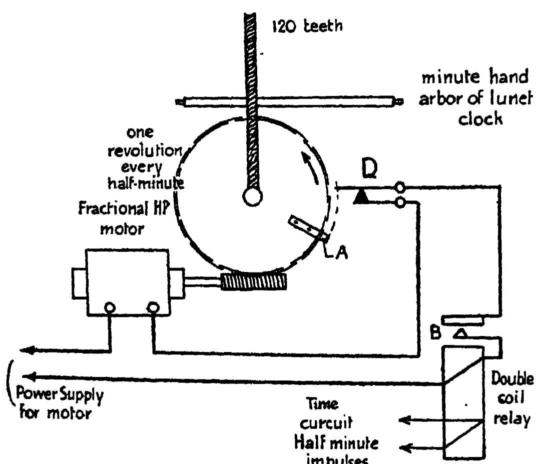


Fig. 27.

practically identical in principle, but seconds are used instead of half-minutes.

But there are other ways in which half-minute impulses may be used to control motion. The subject is almost inexhaustible, and I cannot do more at the end of this chapter than to recommend the thoughtful experimenter to hark back to Bain, Jones, and Ritchie and consider the effect of accurately spaced intervals of uniform wave-shape every half-minute. In a lecture at the British Horological Institute in November, 1929 (*British Horological Journal* of December, 1929), I showed how the synchronous propulsion of half-seconds pendulums from half-minute impulses can be reliably performed by automatic control of the arc and circular error.

CHAPTER VIII

SELF-CONTAINED ELECTRIC CLOCKS

Magnetically operated Pendulums,
Eureka, Féry, Holden, Bulle

OUR short historical review of the work of the earliest inventors of electric clocks, Bain and Wheatstone, led us on to the sympathetic pendulums of R. L. Jones and Ritchie, and thence to the subject of synchronisation, which was dealt with in the last three chapters.

We now come to that most popular application of electricity to horology, the *independent self-contained clock*.

It is easy to disparage a clock which merely goes without being wound up and does nothing to secure uniformity of time-keeping. I have pointed out that they have the defect of their merit; the merit is that they require no winding and the inevitable result is that their correction is neglected. I have heaped ridicule on a consulting electrical engineer who once specified them for use throughout an institution. I have spoken of the subtle fascination which they exercise over the worst type of inventor, the perpetual motion crank, who has filled the Patent files with rubbish, and brought electric clocks into disrepute.

Yet there is a serious side to the subject if you take it seriously. A clock is a mechanism which likes its feed of power in small and regular instalments, and if well-known horological laws are not flagrantly violated, there is always the possibility that it may make a better time-keeper than a key-wound clock of equivalent quality. But even that, to my mind, is hardly sufficient to justify their existence, as their independence is a very real objection, since they are usually left to follow their

own sweet wills, gaining and losing in adjacent rooms until they look foolish.

Electricity has a much greater service to render to horology than that of merely winding up its clocks, and I look upon much of the effort spent in this direction as misplaced ingenuity, so I shall only review in chronological order a few inventions which justify mention, either by their historical or scientific interest, or by their popularity in the countries of their origin.

There are three distinct methods of applying electricity in order to keep a clock going, and they were adopted by the early inventors approximately in the following sequence, expressed as three classes of independent self-contained clocks:—

1. Those whose pendulums are driven by electromagnetic attraction of the bob, (*a*) by contacts made by the pendulum at every vibration or every semi-vibration; (*b*) by occasional impulses to restore the arc of the pendulum when it has fallen below a predetermined minimum.
2. Electric gravity escapements.
3. Electrical re-winding of ordinary clocks.

We have always been accustomed to think of a clock as a storage of power in spring or weight expended through an escapement in keeping a pendulum swinging. In class 1, you see this process absolutely reversed. The power is applied at the other end of the machine; the pendulum is pulled backwards and forwards by an electro-magnet and propels the wheelwork as it swings.

We have always been accustomed to assess the merit of a clock by the skill with which the impulse is imparted to the pendulum with the least possible interference with its natural swing; in other words, we have judged it by its escapement and the quality of its workmanship.

In class 1 you see this theory, and these considerations, thrown to the winds. The pendulum is no longer treated as sacro-sanct and left to swing freely under the dictates of gravity alone, but is pulled to and fro by

impulses which cannot be ranked as constant, and the pendulum itself has to perform the duties of making contact and propelling the wheels and hands.

It is therefore obvious that the clocks in our class 1 cannot possibly contribute to the science of accurate time measurement, but on a small scale with short pendulums and modest prices they have a market and go well enough for domestic use.

Alexander Bain's clock was the first of this kind, 1840-45 (see figs. 2 and 6 in Chapter II). He fixed a coil on the lower end of the pendulum and permanent magnets adjacent to it in the case (or vice-versa) which, in obedience to contacts made by the pendulum itself, attracted it to and fro. The "motion work" of the ordinary clock is, of course, retained, and by means of a simple modification of the escapement, the pendulum drives it instead of the wheelwork driving the pendulum.

The duration of its contact varied inversely with the arc, but there seems to be some doubt whether he knew this or appreciated its value in auto-compensation; certainly he knew nothing of the use of induction for the purpose.

It would not occur to him that the pendulum in its swing set up a counter electro-motive force in restraint of the battery current and that this would be useful in controlling the arc, but for that matter it did not appear to have occurred to anybody until it fell to me to explain it in the "*Electrician*" series of Primers in 1914, when describing Mr. Frank Holden's clock, of which more anon.

In any case all such questions as auto-compensation of arc could not be appropriately considered in a clock in which such niceties are entirely submerged by irregularities caused by bad contacts.

His contact was merely a slide pushed backwards and forwards by the pendulum, with the result that the latter was subject to almost continuous magnetic interference *except* when passing through its zero

position! The energy devoted to the contact was insufficient, its only source being the pendulum itself, and its faults re-acted upon the pendulum at every swing through ragged and uncertain electrical impulses, with the not unnatural result that the invention disappeared long before the close of the nineteenth century.

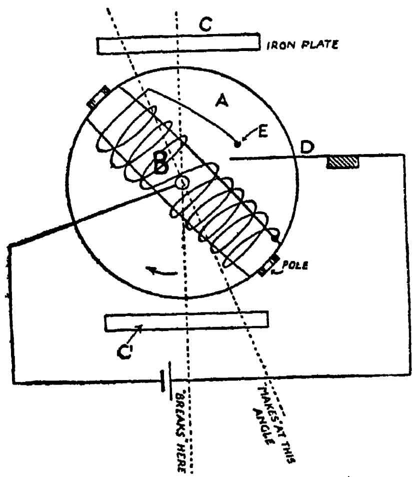


Fig. 28. The Eureka Electric Clock

The attempt of Bentley, of Leicester, to revive it, between the years 1910 and 1913, seems to have met with no better fate in spite of some clever devices for the compensation of arc, and leaves one more convinced than ever that the real fault lies in the nature of the contact, the amount of energy devoted to it, and its source.

The "Eureka" clock, which we illustrate in fig. 28, was an American invention (British Patent 14614, 1906), and, thanks to the enterprise of the brothers Kutnow, it had a good run for five years.

The large and heavy balance wheel A, with a period of $1\frac{1}{4}$ seconds, carries an electro-magnet B, whose core is set diametrically across it. Immediately above and

below the balance wheel are fixed two soft iron armatures C, C1, to which the magnet is attracted. The contact consists of a fixed spring engaging a pin on the balance wheel in such a manner that the circuit is completed in one direction only just as the magnet

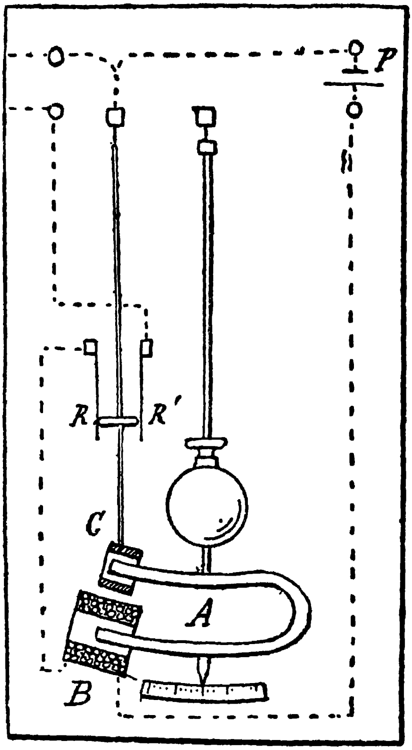


Fig. 29. Professor Charles Féry's Elecric Clock.

enters the field, breaking it when it reaches its maximum velocity. Since there is no inductive effect, the arc varies in direct proportion to the condition of the battery.

The balance wheel was set in ball bearings, and the clock was attractive in appearance and a "safe-goer"

though a poor time-keeper. The speed and mass of the balance wheel provided energy which predominated over the contact, and its periodicity facilitated its development as a striking clock. A few models were made with hour strike, but unfortunately it died a natural death before that addition could be put on the market.

Professor Charles Féry communicated to the Physical Society of France in 1908 the electricity-driven clock illustrated in our fig. 29. His main object was to produce a free pendulum or, as he expressed it, one which touched no solid body during its oscillations. The upper pole of the permanent horse-shoe magnet A attached to the bottom of the pendulum, passed through the coil C of a subsidiary pendulum and inductively impelled it against the contacts R and R_1, thereby closing a circuit from a battery through the coil B which enclosed the lower pole of the horse-shoe; but this is an electrical paradox, because if the contacts affect the subsidiary pendulum they will also affect the work required to drive it and therefore re-act on the main pendulum. Féry used a silver chloride cell and electro-magnets of very high resistance with a view to defying variations of contact resistance. His inventions have survived and are used by Brillié and Le Roy, but not in this form.

In 1909 and 1910, Mr. Frank Holden, M.I.E.E., produced a self-wound clock which was like Professor Féry's in that it was applied to a half-seconds pendulum, and it also ranks as a serious contribution to the subject.

His aim was to concentrate the electro-magnetic impulse upon the pendulum at zero and to leave it altogether free throughout the rest of its path.

Fig. 30 shows the high resistance coil A, narrow and very thin, which constitutes his pendulum, and B, the two horse-shoe permanent magnets through which it swings. Observe the pole pieces designed to concentrate the field at zero. The contact is shown in

fig. 31 and consists of a trailer C which gives an impulse of short duration in each direction just before zero.

Thus all interferences due to contact making and impulse are concentrated at zero, and the clock may be looked upon as a well-designed electro-motor of which

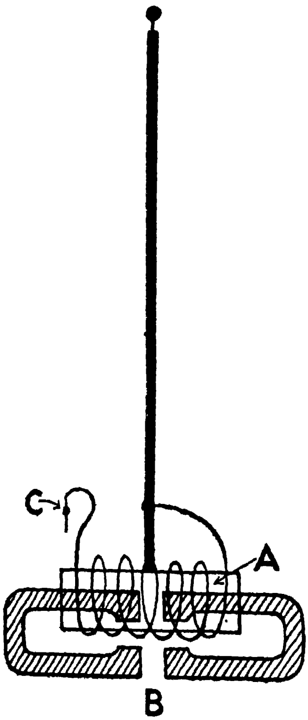


Fig. 30. Mr. Holden's Self-wound Clock.

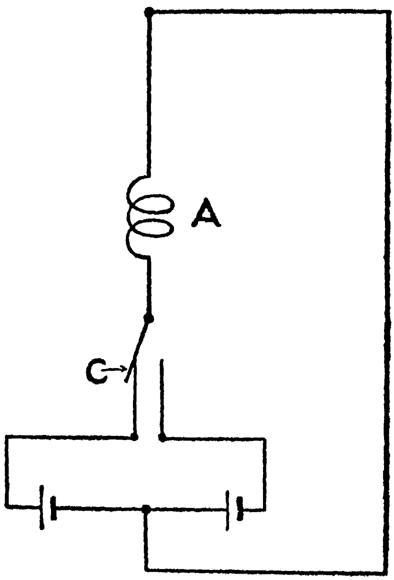


Fig. 31. Contact of Holden Clock.

the flywheel is the pendulum. It is useful to consider it as such in order to appreciate the effect of the counter electro-motive force set up by the movement of a coil in a magnetic field.

Let us assume for a moment that there are no mechanical losses, then the pendulum would swing permanently with an amplitude of such size that the

E.M.F. generated by the coil passing through the magnetic field would be equal to that of the E.M.F. of the battery. It could not exceed that amplitude, for that would involve the pendulum giving up energy to the battery, and it could not be less than that amplitude for that would involve the battery supplying energy to the pendulum, which, by hypothesis, has no losses,

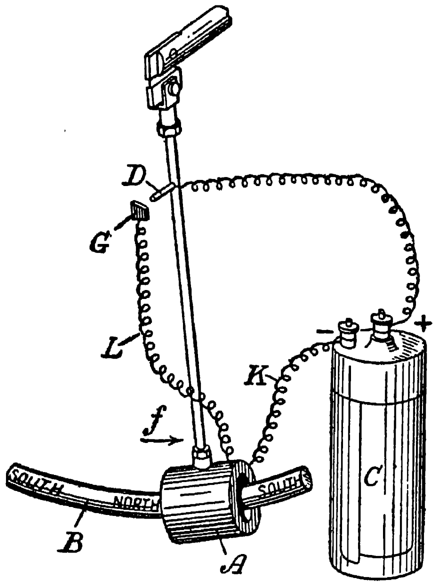


Fig. 32. The Bulle Electric Clock.

and therefore would not require it. In the result, the losses due to air and contact friction and the flexure of the spring are replaced by a very small consumption of current and the arc is fairly constant, though, of course, it is primarily dependent upon the E.M.F. of the battery employed.

The Bulle clock, which has had a great vogue recently, is of a similar type, its original feature being

the arrangement of the permanent magnet with its north pole in the centre, as shown in fig. 32. The contact is indicated diagrammatically, and it will be noticed that, as in the Eureka clock, it is made in one direction only.

M. Favre-Bulle does not appear to rely upon induction for arc compensation, and has recently devised means whereby an abnormally large swing of the pendulum shall short-circuit the driving electro-magnet, but I cannot commend such interferences with a pendulum.

The mere suggestion of a mechanical limitation of arc brings us back to the truth with which we opened our consideration of popular independent electric clocks, that as a class they make no serious contribution to the science of accurate measurement of time.

CHAPTER IX

HIPP'S "BUTTERFLY"

IN the last chapter, I described half-a-dozen typical methods of keeping a pendulum swinging by the electro-magnetic attraction or repulsion of its bob, controlled by contacts made by the pendulum itself at every vibration or semi-vibration, and we have seen that the difficulties inherent in such a method are fundamental, since the merit of the contact, measured in terms of the force expended in making it, must be just exactly that which is robbed from the pendulum at the expense of its time-keeping properties, whilst the impulse itself is an irregular and foul interference with the free action of gravity, demanding artificial means of controlling the arc.

Here, again, we are forced to the conclusion that these fundamentals have never been thoroughly understood by inventors. Had they realised the flagrancy of such violations of horological laws, they would have abjured this type of self-contained clock and explored other methods.

Had they known the work of other inventors and used the knowledge to test the merit of their own fancies, then, if their inventive ability could not rise to anything better than pulling or pushing the pendulum by electro-magnetism from pendulum-made contacts, they would have, at any rate, employed a much superior method of doing it, invented as long ago as 1842.

I refer, of course, to the method devised by Hipp of getting an occasional but a much more powerful contact from a moving pendulum without unduly affecting its freedom. In fig. 33 the pendulum is supported at *x*, and *a* is the armature attached to its lower

end immediately above an electro-magnet *b* fixed in the case. The pillar *c* supports a spring blade *d*, which carries a little pallet, pivoted upon it and swinging

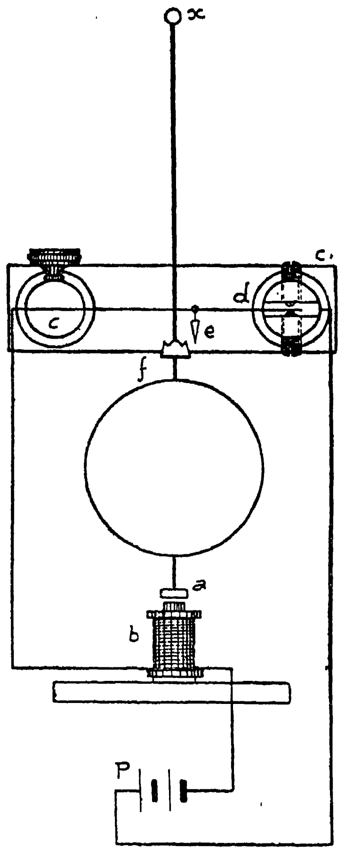


Fig. 33. Hipp's Method of obtaining contact from Moving Pendulum.

freely. The pendulum carries a notched block *f* which normally brushes *e* aside, but catches in it and presses *d* into contact with *c*, when the arc of its vibration has fallen too low. The contact is so adjusted that the magnet attracts the armature at the bottom of the pendulum at exactly the correct phase of its vibration,

thereby increasing the arc and causing the pallet *e* to trail over and beyond the notches until the arc again falls too low.

It is quite true that the energy required to make contact is taken from the pendulum, but this is only occasionally, at wide intervals of time, and it occurs when the pendulum is passing through its zero position, when its kinetic energy is at its greatest and the interference is comparatively innocuous.

Looked upon simply as a method of converting electrical energy into rotary motion, this is probably the most efficient motor ever designed, and it must be remembered that, like ordinary series-wound motors, it is at its greatest efficiency when working at its slowest speed, rotating its driving wheel at the rate of, say one revolution per minute, thereby fulfilling the unique requirement peculiar to clocks. There is no theoretical limit to the amount of power which may be developed by this means. It can be used as readily for large turret clocks as for domestic clocks. It helps itself to whatever current its load requires, and has been effectively used to drive turret clocks by Gent & Co., of Leicester, who applied to it a ½-minute control, under the title of the "waiting train," in 1907, as described in Chapter VII.

Observe that, though fluctuations of battery power vary the value of the impulse, nevertheless the frequency of the impulses is increased automatically and in exact proportion to their lack of strength; hence the average arc is reasonably constant.

But the outstanding merit of the invention is the comparative freedom of the pendulum due to the wide intervals at which contact and impulses take place. Add to this the concentration at zero of such interference as exists, and you get such a good time-keeper that it was actually tried out in observatories for precision purposes.

Dr. Hirsch had one under his care in the Neuchatel

Observatory from 1884 to 1890, and quoted its mean variation of rate in that period as $\pm.03$ sec., saying that it approached the limit of instrumental precision of the means by which time itself is determined.

But we are bound to conclude that it did not quite justify itself in this lofty sphere, since it failed to supplant Riefler in the observatories of the world. Nevertheless, its performance was good enough to give us "furiously to think" about the *real* virtue which enabled it to surpass the achievements of the best Graham dead-beat escapements ever made in England, viz., *the freedom of the pendulum.*

Matthaus Hipp was born in 1813 and died at the ripe old age of eighty in 1893. Favarger, in his book on the applications of electricity to time measurement (new edition, Neuchatel, 1924), says he conceived the idea as early as 1834, which, if true, is a remarkable instance of a young man's early appreciation of the uses of an electro-magnet. He was then only twenty-one, having entered the profession of clockmaker at Saint-Gall, in Switzerland. It was not until 1842, when he was established as a clockmaker at Reutlingen, in Wurtemberg, that he actually produced the invention destined to associate his name with electric clocks for all time. Without doubt, his was the one and only achievement which has survived in what we may conveniently call the Victorian era. His invention was thus contemporary with Wheatstone and Bain, but I doubt whether they ever heard of it. Its first appearance here was in the British Patent, No. 1518, of 1865, as a communication from J. T. Scholte, of Paris. In this patent, the dial motion wheels are driven by a one-sided crutch through a worm gear, an excellent method frequently repeated without acknowledgment. But for that matter, the Hipp "toggle" itself has been unblushingly re-invented a dozen times.

It is suggested that the term "Butterfly" escapement originated with one such invention, viz., that of

Lemoine, of Paris (British Patent, No. 5051, of 1880), who used air resistance rather than gravity for his toggle, by means of a long lightly-pivoted vane terminating in a sail of paper or mica, as shown in fig. 34.

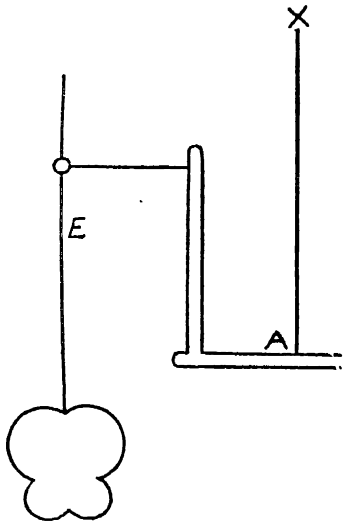


Fig. 34. The "Butterfly" Escapement.

The only part of a pig that a Chicago pork packer cannot use is the squeal; the only part of Lemoine's invention which *has* been used is the word "Butterfly," and I prefer the term Hipp's Butterfly escapement to Hipp's *horloge à palette et contre-palette*, which is its accepted title abroad.

Messrs. Peyer, Favarger & Co., the original manufacturers and successors to the business founded by Dr. Hipp in 1860, and the Telegraph Manufacturing Co., of Neuchatel, have made a large number of Hipp clocks, and they became very popular in their domestic form with a pendulum beating half-seconds, thanks to its simplicity, silence, small consumption of current, and the fact that any battery will keep the clock going until it is almost exhausted, exhibiting a battery warning

meanwhile; but even with these virtues and its good time-keeping it is no longer "on the market" as a self-contained clock in this country: so true is it that there is no serious and permanent demand for clocks which simply go without being wound up and retain their independence.

The horological text-books on the Continent—and there are half-a-dozen in German and French dealing with electric clocks alone—show the Hipp invention in as many different forms, usually with the toggle on the pendulum and the notch on the contact spring, and British inventors have re-designed it repeatedly.

The best design I have seen is that of Mr. H. E. Jones, of the Synchronome Company, illustrated in fig. 35, in which the magnet delivers its impulse to the one-sided crutch, whose normal function is to propel the wheelwork. It will be understood that the armature lever A is pivoted at B, a spot precisely coincident with the pendulum's suspension which is not shown. This direct method of applying the electro-magnetic pull is far more efficient that the indirect attraction of a magnet under the bob.

The Hipp Butterfly escapement is contained in the master clock adopted by the British Post Office, being a survival of the Silent Electric Clock Co., merely as a motor to keep its pendulum swinging, but there are some weighty objections to its use as a master clock which we shall discuss in their proper place. Better methods have been introduced since, but the Post Office authorities find the Hipp Butterfly a simple and reliable means of keeping their pendulum swinging, and if they have failed to take advantage of recent developments and the merits of modern electric time service, which we shall shortly unfold, it must be attributed to the inertia of a Government Department who, having established a standard pattern and practice, hesitate to make changes.

There are other methods by which the failing swing

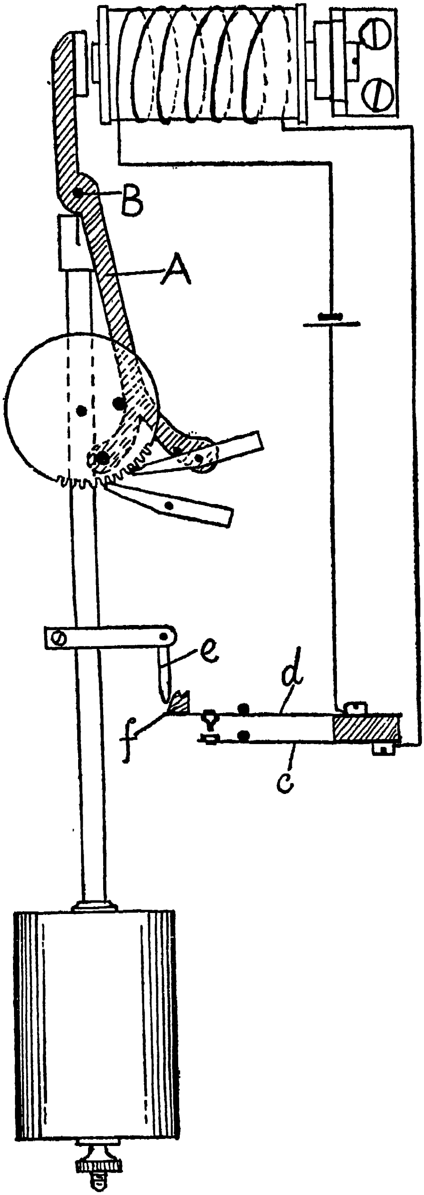


Fig. 35. A recent variation of Hipp.

of a pendulum may be utilised to make contact, and one of these, devised by Herbert Scott, of Bradford, appears to retain all the advantages of the Hipp form. In this clock, illustrated in fig. 36, a click B, carried by the pendulum A, propels a ratchet wheel C, one tooth at

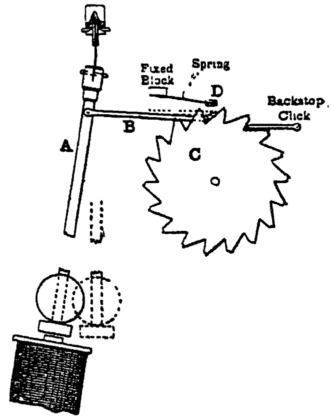


Fig. 36.—Electric Clock by Herbert Scott.
Note how the teeth terminate in a notch, instead of ending in a point.

each complete vibration, and has a contact D fixed close above it. Normally, the click rides free of the contact, but when the arc of the pendulum has fallen a little, it engages in a shelf cut in the top of each tooth, and consequently rides at a higher level and makes contact. But these clocks are no longer to be found. Like all independent clocks, however virtuous individually, they are independent and therefore emblems of selfishness instead of examples of team-work in community service.

CHAPTER X

ELECTRIC GRAVITY ESCAPEMENTS

Shepherd, Froment, Gill

WE have had enough, in the last two chapters, of independent self-contained clocks, kept going by making electro-magnets of their bobs, and pulling and pushing them backwards and forwards. We examined half-a-dozen typical specimens, and saw how one of the earliest was by far the best, viz., Hipp's Butterfly escapement.

So we are free to turn our attention to electric gravity escapements. Our study of these will also take us right back to the early days, the first appearing in a patent of C. Shepherd, No. 12567, of 1849. Lord Grimthorpe describes the system in "Clocks, Watches and Bells" in the following words:—

"Shepherd's clocks, by which it was announced that all the time of the 1851 exhibition was to be kept, seemed more promising, but they soon failed totally there, and the time was kept by Dent's large clock, made from my design, now at King's Cross. In them the electricity was employed to lift a small gravity arm at every alternate beat, which gave the impulse to the pendulum by falling on a pallet like the down-pallet of a dead escapement which had the advantage of giving a constant impulse when it gave any. But, unfortunately, it did not always lift." But we must not take Grimthorpe's criticisms too seriously, for he was no electrician and he completed his sentence thus:—

"And anyone who sets to work to invent electrical clocks must start with this axiom, that every now and then the electricity will fail to lift anything, however small."

Grimthorpe just let it go at that without any investigation as to the root causes of the failures of electric clocks, and I took up the question exactly where and

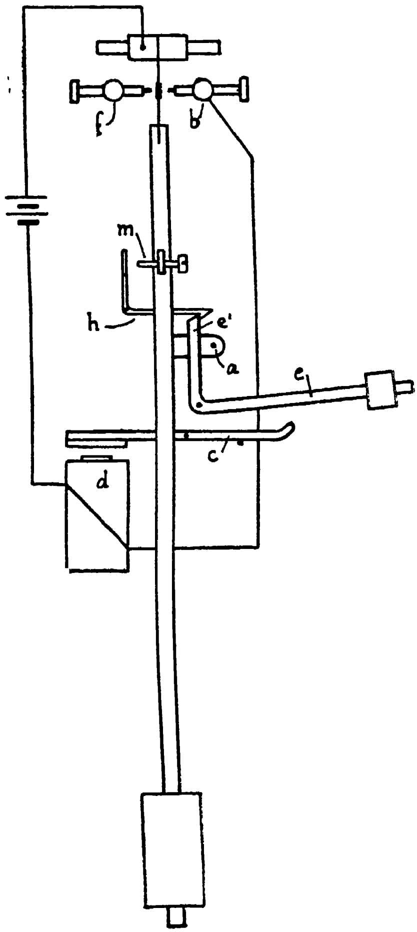


Fig. 37. Diagram of Shepherd's Clock.

when he left it in 1895, determined to find the real causes and origin of these failures.

Fig. 37 is a simplified diagram of Shepherd's clock.

A right-angled gravity arm *e* is pivoted in front of the pendulum with its vertical arm e^1 normally held by the catch *h*. The pendulum carries a screw *m* which engages *h*, also an impulse pin *a* which receives e^1 when it falls. At the end of the pendulum's excursion to the right, the contact plate on the suspension spring touches the terminal *b*, which closes the circuit of magnet *d* and resets *e* by means of armature lever *c*. The contact *f* operates a circuit of electrical impulse dials.

Thus the pendulum has all and every kind of work to do and does it in the worst possible way. It charges into fixed contact points at the ends of its swing and unlatches its gravity arm in the same way, whilst the whole of the energy required to make contact is directly robbed from it.

Shepherd was established at 53 Leadenhall Street, but he lived at Hendon, where he secured the help of a wealthy and influential resident in Mr. J. F. Pawson, who had the system installed in his firm's warehouse at St. Paul's Churchyard—now Messrs. Pawsons and Leafs, Ltd.—where, however, it soon failed. But in the meantime and within twelve months of filing his patent, Shepherd had the good fortune to secure the interest of a much more valuable patron in the Astronomer Royal, Sir George Airy. He installed it, with some slight ameliorations, such as spring contacts, in Greenwich Observatory in 1850 as a master clock to operate a group of electrical impulse dials.

In his Autobiography, Sir George Airy refers to it under the year 1852:—

"I established eight sympathetic clocks in the Royal Observatory, one of which, outside the entrance gate, had a large dial with Shepherd's name as patentee. Exception was taken to this by the solicitor of a Mr. Bain, who had busied himself about galvanic clocks. After much correspondence, I agreed to remove Shepherd's name till Bain had legally established his

claim. This, however, was never done, and in 1853 Shepherd's name was restored."

Shepherd's famous clock has a 24 hour dial on the right of the main gate, at the Observatory. His step by step movement is placed behind it on the other side of the wall, facing into the forecourt. This movement is almost as large as the dial, and is about the size of a modern 1 h.p. electro-motor. Its work would be done to-day by a movement no larger than the galvanometer at the lower corner on the right.

Some years ago, the number of Shepherd's coils was halved and the diameter of what remain has been reduced, but its general appearance is unaltered and it is going, as he set it going, nearly eighty years ago, within a yard or two of that invisible line which the world knows as *Longitude nought*, and of the great Transit circle telescope where Greenwich Mean Time originates. It must shortly give place to modern methods; at four-score years it will have earned its rest, and let us hope it will find it in a National Museum—some Westminster Abbey of pioneer inventions.

But this and the other electrical impulse dials in the same group have not been driven by their original master for many a long year. The inventor and Sir George Airy himself expected great things of it as a precision regulator, but, if you will refer to fig. 37 again, you will see how primitive and crude it is. It leaves us wondering how Airy, whose papers on pendulum mathematics and the theory of escapements have long since been recognised as classics, could have entertained any such hopes.

He failed to realise that the reliability of an electrical contact is mainly dependent upon the force expended in making it, and it did not occur to anyone at that date that that force could be obtained from anything but the pendulum itself.

So far as we have gone in our study of the applications of electricity to horology, we have had no occasion to

be puffed up over our achievements. Breguet proved himself our master in synchronisation, and Hipp taught us how to make a clock with an electro-magnetic bob.

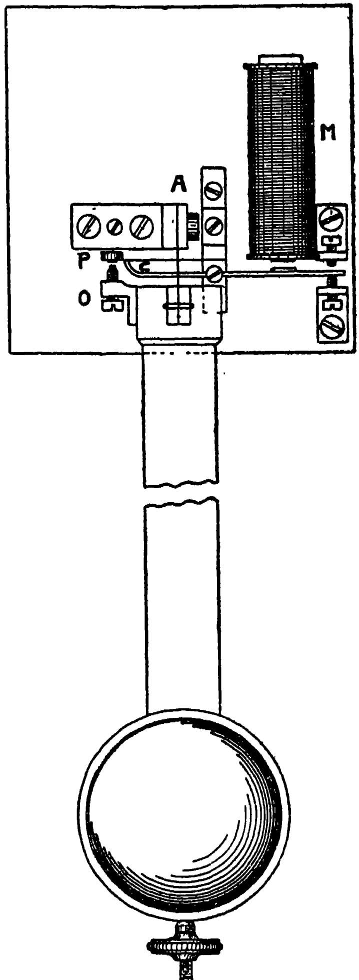


Fig. 41. Froment's Pendulum.

Now, alas! we must cross the Channel again for a better electric gravity escapement. In 1854, Froment

devised the pendulum illustrated in fig. 41. It is driven by a gravity or spring arm P, which behaves exactly like its counterpart in a Bloxam or Grimthorpe gravity escapement, that is to say, the pendulum picks P up by screw O, finishes its swing in company, but on its return does not part from P until the latter has reached a point below that at which the pendulum found it, the difference being the impulse. This is accomplished by the simple expedient of moving the stop or limit lever C by an electro-magnet M, the current being passed through the pendulum (via A and O) and the gravity arm P; already in mechanical contact, they constitute the electrical contact, and the magnet M holds C in the lower position so long as P is free to give its impulse.

In attributing this to Froment, I follow Du Moncel's *Exposé des Applications d'Electricité*, published in 1855, but other names have been associated with it, such as Liais and Verité and later on Tiede and Knoblick, whilst Sir David Gill, unaware of any anticipation, described it to the British Association in 1880 and used it in his ill-fated Cape Observatory clock. Finally, Mr. Cottingham made one for the Edinburgh Observatory during the war, which was the subject of a very interesting mathematical analysis by Professor R. A. Sampson, F.R.S., the Royal Astronomer for Scotland, to be found in the Proceedings of the Royal Society of Edinburgh for 1918.

The late Sir David Gill, who in his youth was apprenticed as a clockmaker to the well-known Clerkenwell firm of Messrs. R. Haswell & Sons, was appointed by the British Association in 1879, with Sir Howard Grubb, Professor Forbes and Mr. Ginningham, as a committee to consider the question of improvements in astronomical clocks. He set himself and his colleagues the terms of reference in the masterly manner we would expect from him, thus:—

"To maintain the motion of a free pendulum in a uniform arc, when the pendulum is kept in uniform

pressure and temperature, and to record the number of vibrations which the pendulum performs, is to realise the conditions which constitute a perfect clock."

And he produced the device illustrated in fig. 42 as a perfect solution of the problem, with one reservation only—the contact—whose reliability was doubted. It will be observed that fig. 42 is identical in principle with fig. 41, so I have used the same reference letters and need not repeat the description.

Unlike Shepherd's, the pendulum is not called upon for anything, not even to unlatch the maintenance, which is what a pendulum expects to have to do for any gravity escapement. If it were not that it picks up a gravity arm and returns with it to a lower point, it could be called a free pendulum. Where, then, does the contact energy come from if it does not come from the pendulum? Primarily from the electro-magnet, of course, since it is a self-going or electrically-propelled pendulum, but the point is how does the energy reach its job of contact-making? Is it first put into the pendulum and then taken out of it as in Shepherd's? No, in this case the energy is *transmitted through the surfaces of the contact* in the act of driving the pendulum.

Neither its original inventor, nor a single one of its re-inventors, ever gave a word or sign to show that they understood this fundamental principle or were aware of its importance, and they reaped little advantage from it, since the energy is too diffused to be of any considerable use in improving the contact, being spread over the whole period of the operation, viz., about one-third of the total time measured, throughout the whole of which period the current is being consumed.

Sir David Gill failed to make anything of this clock either here or at the Cape, where much money was spent upon it and its constant temperature chamber—a water jacket.

The freeing of the pendulum from extraneous work

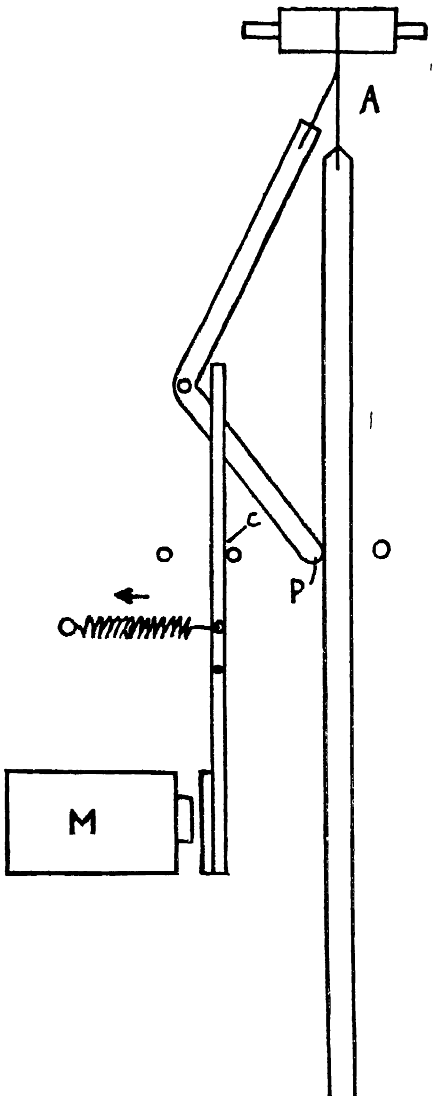


Fig. 42. The Problem "solved" by the late Sir David Gill.

was good; transmission of energy through the contact was good; but these alone could not suffice, as we shall see in a later chapter.

The interference due to the escapement was still excessive, and the energy devoted to making contact was insufficient.

Unfortunately, Gill and his colleagues took the wrong track in their efforts to deal with the contact difficulty. They were unconscious of the principle of transmission of energy through the contacts although they were using it, and instead of concentrating upon that principle and developing its application, they assumed that the energy *must* come from the pendulum, and that the pendulum alone could discharge the impulse, so they wandered off into the use of Crookes' vacuum tubes containing radiometer arms as light relays, much as we use selenium cells to-day.

Those who have done me the honour to follow my contributions to this subject will realise that I set out in 1895 in the diametrically opposite direction, recognising that switching was a brute-force operation and that it must be accomplished without interfering with the pendulum.

I ought to add that Favarger & Co., of Neuchatel, make a very satisfactory regulator on the Froment principle, but no Froment clock can ever quite reach the front rank, its performance being limited by the nature of its escapement. It is as good as the best Grimthorpe gravity escapement, perhaps a little better, because it has no unlocking to perform, but that is just not good enough.

CHAPTER XI

ELECTRIC GRAVITY ESCAPEMENTS (Contd.)

Féry, Prince, Robertson, Steuart

"A THING of beauty is a joy for ever." In the realm of Art this savours of exaggeration and poetic licence. It is more true to me in the field of Mechanics. So far, we have found three inventions of such distinction that they will continue to delight generations yet unborn. I have in mind *Breguet's* Horloge-mère sympathique, whose parental devotion to the erring watch was described in chapter V; the *Hipp* Butterfly escapement because of the masterly manner in which it makes a firm electric contact with the least interference, and that interference concentrated at zero; and the *Froment* gravity escapement described in the last chapter. I doubt whether the latter inventor understood its intrinsic merits himself, but the fact remains that his was the first gravity escapement whose pendulum was not called upon to unlock the maintenance nor to provide power for making a contact.

It is to be regretted that so many subsequent inventors failed to find this foundation stone and to build upon it, but blundered in ignorance upon the same idea, putting it in a different or indifferent form without adding anything to it, or benefiting from the precious jewel which it contained.

I will refrain from putting them in the pillory, and will describe four interesting variations only, viz., those of Féry, Robertson, Steuart and Prince.

Fig. 43 is reproduced from Prof. Chas. Féry's British Patent, No. 4889, of 1911, and shows how the impulse and interference is transferred from the end to the middle of the pendulum's swing.

The roller O presses the spring P into contact with the armature C, with the result that the spring P imparts an impulse to the pendulum immediately after zero.

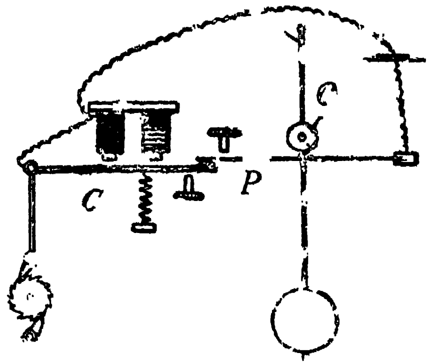
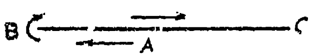


Fig. 43. Féry's adaptation of Froment. Impulse given in middle of Pendulum's swing.

Froment's impulse, as we have seen in figs. 41 and 42, is that of the stereotyped gravity escapement. The pendulum, in travelling to the left, picks up the gravity



arm at A, carries it to B, and returns with it to C, the difference between B A and B C being the impulse.

Féry's improvement upon it clearly demonstrates the vice of the lifting of the gravity arm from A to B and its return to A, for, now that it takes the form of depressing P, in fig. 43, we see that it is equivalent to a mechanical unlocking of the maintenance and causes no less interference, the only merit being that it is nearer zero.

Professor David Robertson achieved a similar result by a link action in the clock he devised in 1924 for the control of the electrical striking of the hours on the Bell "Great George" of the new Bristol University. It

will be observed in fig. 44 that the impulse is given by a weighted cradle which is free to fall whilst it is in mechanical and electrical contact with the impulse lever.

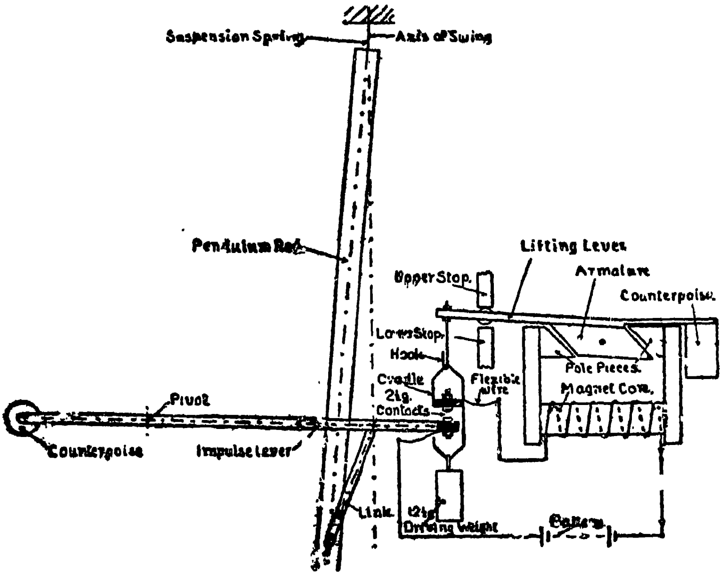


Fig. 44. Professor Robertson. Impulse given by Weighted Cradle.

I have not heard of any reproduction of these devices and I doubt their value, particularly the latter, whose pendulum is never free. The weight and cage has an interesting prototype in Mr. A. T. Hare's pendulum, Patent No. 113,501, of 1917, but, as that is essentially a mechanical escapement, I must not be tempted to deal with it here.

In 1921, Mr. Alex. Steuart, of Edinburgh, hit upon a most ingenious plan for using a rotary motor to replace the gravity arm, thereby controlling its speed. Fig. 45 is taken from his Patent No. 202,139, but is lettered to correspond with figs. 41 and 42 in the last chapter to which the reader should refer. Observe that the pendulum, the gravity arm P and lever C are the

same in both, but that P, after driving the pendulum, falls on the right-hand stop and short-circuits the resistance of a continuously running motor, thereby

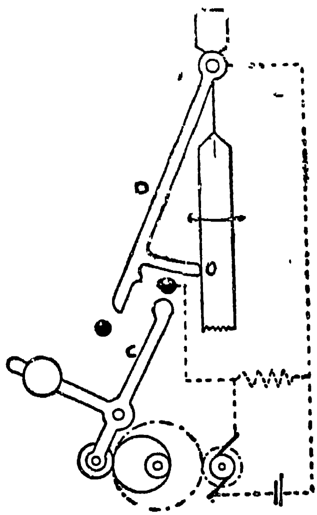


Fig. 45. Steuart's Patent. Rotary Motor used instead of magnet.

quickening it for a period, the beginning of which is dictated by the pendulum and the end of which is limited by the motor itself in the act of replacing the gravity arm by a geared cam.

The motor may be looked upon as a synchronised slave clock whose synchronising signal is given by the fundamental pendulum which dictates the precise point of time at which the gravity arm finishes its job of imparting the impulse and signalises the event by making contact with the stop.

It is a wholly delightful method of putting a continuously running motor under the direct control of a pendulum, and has all the attributes of finality. Its power is unlimited, it is silent in action, and its uses are obvious; it should replace the conical pendulum wherever continuous motion is required, as in chronographs and

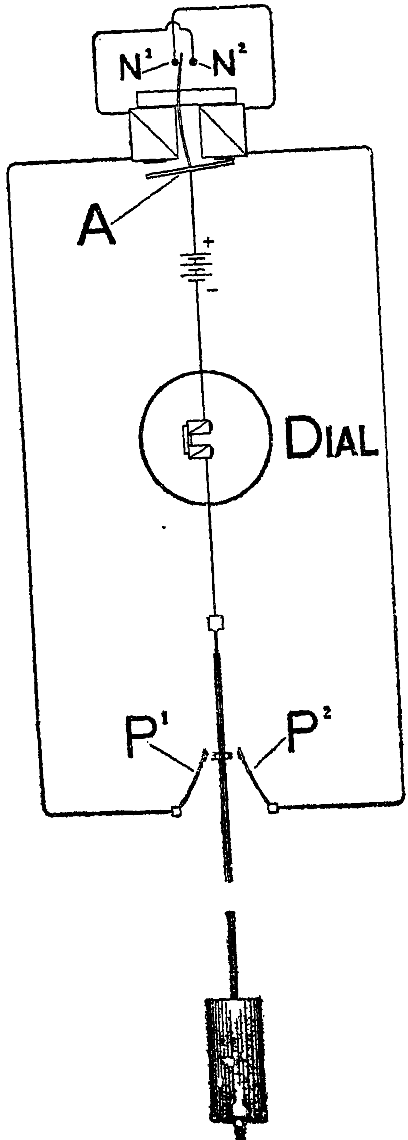


Fig. 46. Prince's Method. Pendulum operates a change-over Switch.

telescopes. If it fails to achieve popularity as a self-going clock of exceptional precision, it will be because independent clocks, however good, are not wanted, and perhaps because of the difficulty of providing a small low voltage motor to run reliably and for long periods off a primary battery. When we come to consider the "Telechron" clock, you will see that a low power synchronous motor continuously running on the domestic alternating current supply service is a different problem altogether, and one which has been solved.

There is no transmission of energy through the Steuart contact, but since it is only called upon to short-circuit a resistance and an occasional miss would not matter, it is probably good enough; like all the contacts in the Froment family, however, its duration is very long.

Major Prince (Patent No. 206,186, of 1922) attacked this difficulty in an ingenious way by means of a reverser, which is illustrated diagrammatically in fig. 46.

The pendulum-made contacts at P^1 and P^2 are the equivalent of Shepherd (fig. 37, last chapter), but consist of very light springs. When one circuit is closed by the pendulum on one side against spring P^1 or P^2, it is immediately opened at N^1 or N^2 by the polarized armature A and left ready for reversal by the other. It is a change-over switch operated by a momentary contact made by the pendulum at every semi-vibration. The "reverser" also raises a gravity or spring impulse as in Froment.

I am not here dealing with the Princeps system of electrical impulse dials, but only with the master clock as an interesting adaptation of the Froment principle, on which it is an improvement in so far as it reduces the duration of the contact.

The consideration of systems of electrical impulse dials and the master clocks which operate them must be deferred to a later chapter. On account of this imperative demand of classification, I must refrain from

referring here to the "Synchronome" system, which is primarily a half-minute system of dial propulsion, but which nevertheless has made a substantial contribution to the subject we have been dealing with—electric gravity escapements—in which impulses are given to the pendulum at every, or every other, swing.

The genesis of this system will appear in due course when dealing with the next section of our subject, viz., that class of self-contained clocks in which an ordinary escapement is retained and the motive power is the re-winding of a spring or weight by an electro-magnet, whilst its development will take us again into the field of electric gravity escapements and will show how a uniform impulse may be imparted at zero without any of the drawbacks and disadvantages we have discussed, such as long duration of contacts and consequent diffusion of the energy required to secure their reliability.

CHAPTER XII

SELF-WOUND CLOCKS

Pond, Reclûs, Perret, Van der Plancke, Self-winding Clock Co., Möller, Webber, Murday, Chandler, Palmer, Aron, Hennequin, Hope-Jones and Bowell

THIS, our third division—or, rather, sub-division of that great class embracing all electric clocks which retain their independence and simply go without being wound up—concerns the method which has been most generally adopted. No wonder that the simplicity of the idea has attracted hundreds of inventors who set themselves the apparently easy task of arranging a contact on one of the wheels of the clock to control an electro-magnet which shall store a little power in spring or weight sufficient to keep it going until the action repeats itself. There are people who still think this is original, though it has been done in almost every conceivable manner.

The self-wound clocks of this class selected for description are arranged, for the sake of clearness, in a sequence of natural evolution, to show the advance from the crude to the more perfect, and the survival of the fittest. Where this coincides with the order in which they were actually produced it must be attributed to accident, for, in spite of the publicity afforded by patents, technical journals and the proceedings of learned societies, it must be confessed that the ignorance of most inventors of the work of their predecessors is profound.

Unlike the last two classes we have been discussing, clocks of this kind contain a train of wheels communicating impulses to a balance wheel or pendulum by means of an escapement in the ordinary way. A

circuit-closing device is usually applied to some part of the train of revolving wheel-work, and this contact controls the action of an electro-magnet or motor, which raises the weight or re-winds the spring. In its crudest form the contact is made by a pin on one of the wheels, which at each revolution meets a spring mounted in its path. The "make" will be slow, the duration will be difficult to determine precisely, and if the spring is adjusted hard it may stop the clock, while if it is light the contact will be unreliable.

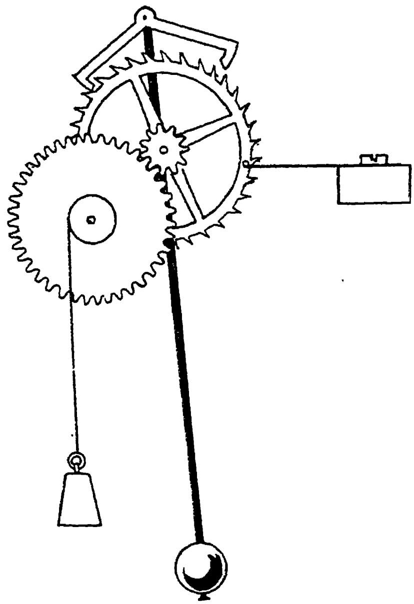


Fig. 47. Simplemindedness. Applying a Contact to a Scape Wheel.

Fig. 47 will serve to illustrate this first step of the child-like mind which is typical of the average inventor of electric clocks. It is the sort of thing that you and I did in the nursery when our parents wanted a bell to waken the servants.

The second step is to provide an electro-magnet to lift a weight or charge a spring.

In case the remarks I made *à propos* of Wheatstone's clock in Chapter III were missed, let me repeat the obvious truth that we are between the devil of a stopped clock and the deep sea of a failing contact, since the whole of the energy is robbed from the wheel-work.

If one *must* make a contact from the gently moving wheels of a clock—and there are occasions where and when circumstances demand it—let us follow the example of Professor Arzberger, of Brünn, who devised,

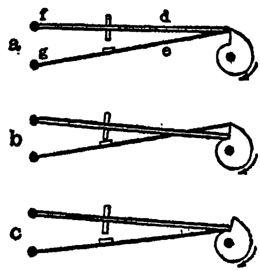


Fig. 48. A Better way of applying a contact to Wheelwork.

in 1870, the cam and two levers illustrated in fig. 48. They are lettered *d* and *e*, pivoted at *f* and *g*, with their free ends lying side by side on the cam, and are shown in three positions: just before making contact (*a*), in contact (*b*) and just after the break (*c*). This arrangement provides a quick make and break, and the duration of the contact is exactly determined by the difference in length of the two arms and the speed of rotation of the cam. It also equalises the friction on the train; but the principle is the same, the whole of the energy devoted to the purpose of the contact being obtained from the wheel-work.

The contacts in the following clocks are all modifications of the same principle:—

The self-winding clock of Chester H. Pond, of Brooklyn, N.Y., contained a little rotary motor which

wound up a spring, in response to a contact made by the centre wheel, every hour. An attempt to introduce this into England in 1886 met with small success, but the Self-Winding Clock Co., of New York, has since adopted an improved pattern in which the motor takes the form of a vibrating bell-hammer with pawl and ratchet, operating at more frequent intervals.

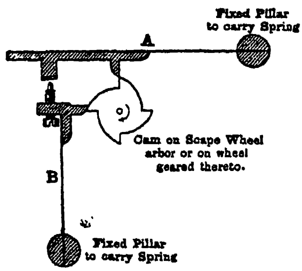


Fig. 49. The Contact of Victor Reclûs.

In the clock of Victor Reclûs, of Paris, the periodic contact is obtained by the action of cams on springs, as shown in fig. 49. The cams are mounted on one of the rotating arbors of the clock train, and are normally engaged in pressing aside the two springs A and B. The spring A falls off first and makes contact; the spring B falls off a second or two later and breaks it.

The contacts in the self-wound clock of David Perret, of Neuchatel, are also obtained by springs deflected by the wheel-work. In this case the centre wheel operates two contacts in series, one for the make and the other for the break.

Van der Plancke's clock, of La Precision Cie., of Brussels, makes its contact in the same way, and the armature of its magnet is shaped like a small hammer, adapted to hit a pin on a weighted flywheel, thereby kicking it round one revolution and storing energy in a spring.

Many more examples could be named whose contacts work on the same principle, but the above will

suffice for the purpose of illustration. It will be observed that in all of them the energy devoted to contact-making is just that amount which is robbed from the gently moving wheel-work. With a view to reducing this stolen energy to the smallest amount, some inventors have used mercury contacts in tilted tubes, but even when the spark is carefully eliminated by means of condensers, as in those of the Self-Winding Clock Co., of Bristol, Connecticut, and of Svenska, of Stockholm, it can hardly be considered a satisfactory solution.

Some source of considerable power, other than the wheel-work of the clock, for the purposes of the contact is desirable. Now, the means by which the electro-magnet re-winds the clock by storing energy in a spring or weight is invariably a heavy moving armature. Not unnaturally, therefore, the idea has suggested itself of using it to reinforce the contact by increasing the rub or pressure upon the surfaces which have to transmit the electric current. The uniformity of the going power is not seriously disturbed if the armature devotes some of its energy to contact purposes and stores what remains in the spring or weight.

Fig. 50 shows a self-winding device of this class by Mr. A. B. Webber, of the Standard Time Co., Ltd., taken from his Patent No. 8094, of 1902. The ratchet lever *b* having the pawl *d* is pulled by the spring *f* to drive the ratchet wheel *e*, and an armature *j* attached to it is thus lifted from the poles of an electro-magnet *c*, while a spring terminal *a* attached to the armature is kept off a fixed terminal *h* because a pin a^1 upon it feels a guide-plate *g*. The circuit being closed when the pin is clear of the guide-plate, the electro-magnet draws the ratchet lever down against the guide, and the pin travels behind the latter, till it escapes again to the front.

This device was anticipated in principle by Möller, of Berlin (Patent No. 10960, of 1901), the only difference being that in Möller's the spring is fixed to the frame and the inclined projections are mounted on the armature,

while in Webber's the spring is mounted on the armature and the inclined stop is a fixture.

The German clock was well-made and achieved a commercial career in its own country. In many respects

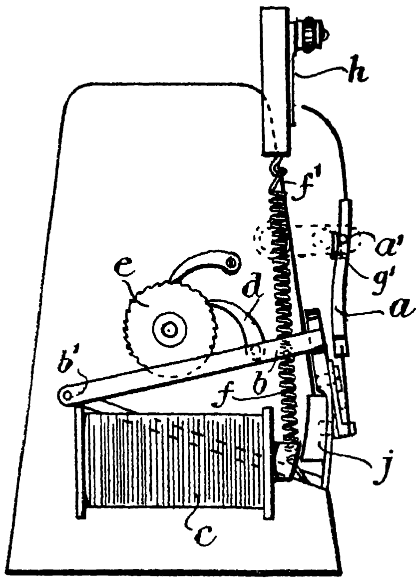


Fig. 50. A. B. Webber's Self-wound Clock.

Webber's was better, but was born to blush unseen in our desert air where independent self-wound clocks are not appreciated.

Self-wound clocks by T. J. Murday, F. A. Chandler and S. Palmer are similar in principle, but with every variety of constructional detail. Dr. Aron's self-winding action, which has been applied more to electricity meters than to clocks, also derives its contact-making energy from the moving armature, but it is sufficiently distinctive to justify illustration in fig. 51, in which the driving click A, mounted on the armature B, drives the main wheel of the clock by means of the spring C. The carrier D, with insulated blade E and contact blade

F, is in a state of unstable equilibrium, and is adapted to be flung in one direction or another by the spring G when the centre pin H on the armature has moved

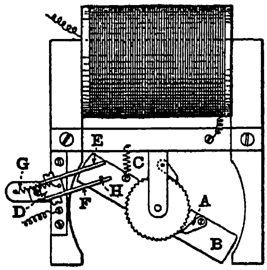


Fig. 51. Dr. Aron's Self-winding Clock contact.

it past the dead centre. The self-wound clock of Hennequin, of Compiègne, is similar in principle.

It will be noticed that while the above constitute a distinct advance, in that the greater part of the energy required to make contact is taken from the armature in its return to the magnet, there still remains a certain amount of work to be done by the wheel-work, or, which amounts to the same thing, the spring or weight which is driving it, with consequent variation of the power applied to the escapement.

In 1895, in association with Mr. G. B. Bowell, I pointed out, in a lecture before the British Horological Institute, that it was unnecessary for the wheel-work or its driving power to take *any* share in the work of contact-making, and described a method by which the whole of the energy expended in keeping the clock going is mechanically transmitted through the surfaces of the contact. This device is shown in fig. 52, in which the weighted lever A turns the wheel-work in falling. When it reaches the contact screw in the armature E the circuit is closed, and the magnet C replaces the weight by throwing it up, the break being caused by the momentum of the lever, whose mass is intentionally

increased. Though this system appears to be the logical result of progress upon the lines I have indicated, and finally disposes of the difficulty of obtaining a reliable

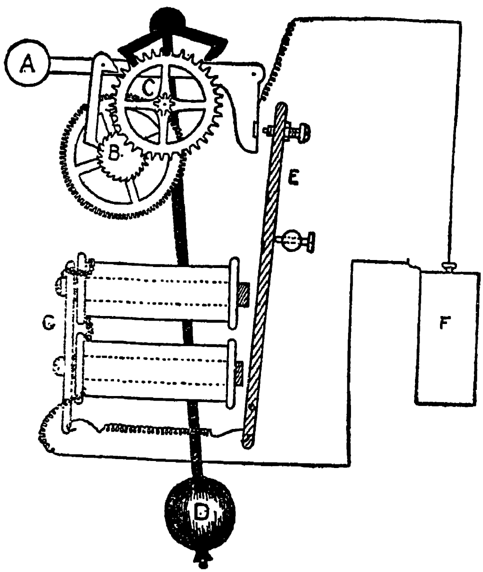


Fig. 52. The Synchronome Switch in its earliest form.

contact without the least interference with the time-keeping properties of a clock, it was actually published before several of those I have named, owing, no doubt, to the isolation of individual inventors.

The main object of the device as I presented it in 1895 was to serve as a master clock to transmit electrical impulses every half-minute for the operation of circuits of step-by-step dials.

CHAPTER XIII

SELF-WOUND CLOCKS (Cont.)

Fuld, Synchronome, the derivation of the name. Huyghen's Endless Chain. Telechron

WHEN the Synchronome Remontoire, illustrated in fig. 52 of the last chapter, is used as a self-winding action for an independent clock, it has been customary to apply it to a wheel with a fine-toothed ratchet or milled edge on the arbor of the wheel next the 'scapewheel, as shown in fig. 53. This wheel is loose on its arbor and only connected with the gear wheel by the maintenance or concussion spring D, which is in action whilst the gravity arm is being thrown up by the electro-magnet, the backstop click E holding the wheel in the meantime. The pivoting of the armature between the poles is conducive to silence in action, at the cost of some efficiency. The momentum imparted to the gravity lever A by the armature will carry it up a distance proportionate to the strength of the battery at the moment.

On the expiry of the German Patent, Riefler, of Munich, adopted it for his precision clocks, which, being in airtight cases for constant air pressure, naturally demand electric self-winding, and he still uses it. In 1905 Harry Fuld, of Frankfurt, introduced it as a popular self-wound clock, but in spite of its good time-keeping and reliable contact the Synchronome Remontoire is not necessarily ideal for such a purpose. The difficulty is one of current supply; one must take into consideration the source of electricity available and the suitability of the load.

What is the consumption of current of a clock of this type? Obviously very small, because the electrical

contact is of such short duration and occurs so infrequently. The duration is dependent upon the time-

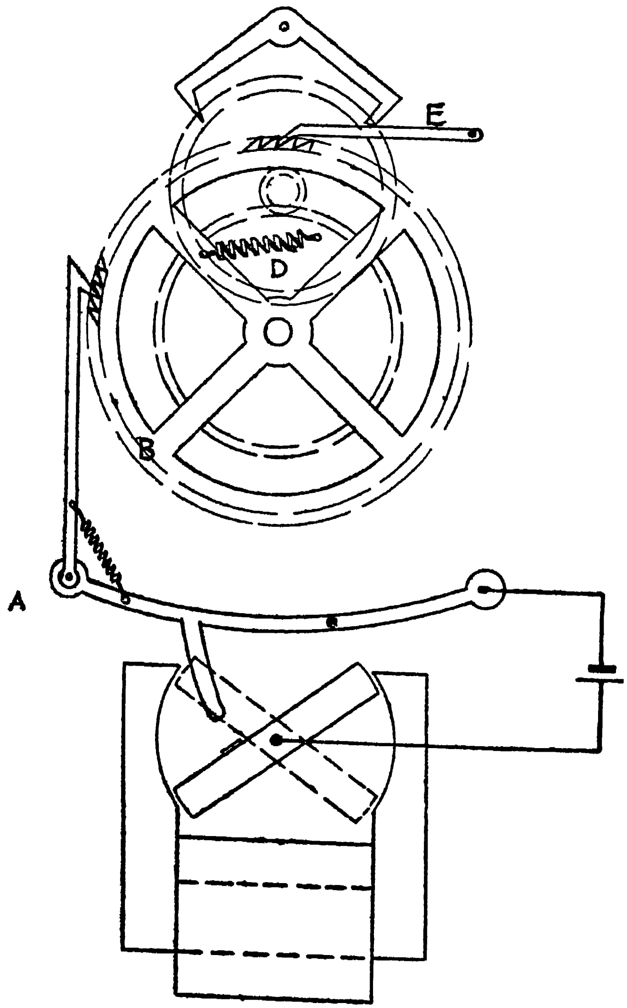


Fig. 53. The Synchronome Remontoire.

constant of the electro-magnet and the moment of inertia of the armature and lever, and may be estimated

at one-twentieth part of a second. If the Remontoire operates once a minute, the following sum, $60 \times 24 \times 365$, gives us 525,600 as the number of contacts in the year and, if their duration is ·05 of a second, the total period of closed contact will be only 7·3 hours per annum.

The only practical source of electrical energy in a popular self-wound clock is a dry cell incorporated in its case. Such a battery may be capable of yielding 100 ampere-hours *on a suitable load in a suitable time*.

Now, seven hours in a year is altogether too short a time in which to obtain a reasonable amount of energy from a given dry cell even at the highest discharge rate practicable, and you are limited in the latter by the internal resistance of any dry cell as a result of natural deterioration and drying up.

Suppose we make the current rate one-third of an ampere, than we shall only be taking $2\frac{1}{2}$ ampere-hours per annum, or $2\frac{1}{2}$ per cent. of the energy the cell is capable of yielding.

Thus from its very nature the Synchronome Remontoire is not well adapted to take the best service out of a battery during its natural life. It is here where other independent self-maintained clocks distinguish themselves, such as those of Holden or Bulle, since the electrical conditions applying to all clocks whose pendulums are propelled by direct electro-magnetic attraction are reversed; their bobbins are wound to a high resistance; their current rate is small and the contact time-factor is comparatively long. And these practical considerations are of more importance in such a commercial article as we are discussing than great accuracy of time-keeping. I have already pointed out that Hipp's clock will take the last ounce of useful energy out of any battery to which it is connected.

When, however, the Synchronome Remontoire is used for the primary purpose for which it was invented as a transmitter of electrical impulses to operate circuits

of dials, these considerations disappear and its merits as a time-keeper and as a switch come into prominence.

The ratchet wheel B is then provided with that number of teeth which results in a self-winding or Remontoire action every half-minute; thus, if the wheel engaging the 'scape wheel pinion (the "third" wheel of an ordinary key-wound clock train) revolves once in 7½ minutes, the ratchet will have 15 teeth.

Introduced in this form in 1895, it held the field in England until 1905, during which decade it ousted such half-hearted attempts as had been made to exploit several Continental and American inventions.

I have often been asked for the derivation of the trade name "Synchronome," under which the system was launched. It is derived from the three Greek words —*syn*, with; *chronos*, time; *nomos*, law; συν χρονου νομω, *i.e.*, in accordance with the law of time. These three words

σ υ ν χ ρ ο ν ο μ ω
are run together, thus: S Y N C H R O N O M E and this incidentally reveals the origin of our verb *to synchronise*.

A little knowledge is a dangerous thing; I recently came across a Limited Company who have based their name upon a word closely resembling it, but with the root CHROM instead of CHRON, imagining that it still indicated time-keeping, or clocks, or synchronising, or something of that kind, whereas, of course, it could only suggest *colour*. Such floundering among Greek derivatives would be merely ludicrous if it were not harmful to the unlettered, and apt to confuse the unthinking by its apparent similarity. It reminds one of the schoolboy's howler—the marriage customs of the ancient Greeks were that every man had but one wife, and they called it—MONOTONY!

At this date, thirty-five years after its introduction, it is interesting to recall what little notice was taken of the first Synchronome invention.

The principle involved, the transmission of energy

through the surfaces of the contact, was a fundamental one, as also was the use of self-induction to dictate the duration of the contact, which will be explained later on, and I acclaimed them as such, but they commanded little attention at the time, and even now they are not realised on the Continent nor in America; yet they are at the root of the whole matter, and the recent breaking of the world's records for accuracy of time measurement at Greenwich and other Observatories by the Synchronome Free Pendulum designed by Mr. Shortt, is based upon them. They are the first of a series of principles on which an industry has been founded.

We cannot leave the subject of self-wound clocks without reference to the Huyghen's endless chain, and the happy way in which it can be used to harness an electro-motor to a turret clock. Any mechanical turret clock may be relieved of its heavy driving weights, the tedious winding of its long wire ropes, and the attendant risks by the simple method illustrated in fig. 54. All that is wanted is some bicycle gear and sprocket wheels and a cycle chain supporting a comparatively small weight. The winding barrel and great wheel are dispensed with, and the chain is applied to a wheel A next, or next but one, to the escape wheel B. The weight C itself operates the snap switch D, on its rise and fall, thereby calling upon the electro-motor to wind it up by the wheel E whenever required, the torque on the going train being uniform and continuous. F is a jockey pulley and weight to keep the chain taut.

In one such application a weight of 240 lbs. falling 60 feet, a storage of 14,400 ft.-lbs., was substituted by a weight of 60 lbs. falling 17 inches, a storage of only 85 ft.-lbs.

Visiting famous turret clocks and carillons was always a hobby of mine and one could never climb the belfry of Bruges without sympathising with the clock-winders and wishing to relieve them of their monotonous task. I recommended the adoption of this method for self-

winding the Westminster clock in the days when it was still a day's work for two men twice a week, but

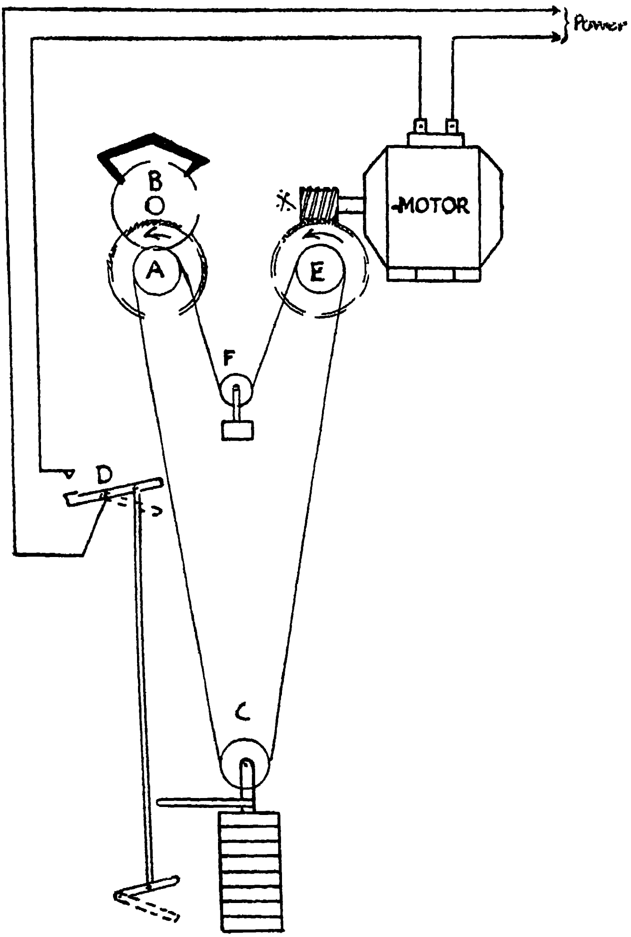


Fig. 54. The Huyghen's Endless Chain principle used with an Electro-motor for winding Turret Clocks.

H.M. Office of Works were apathetic. Both these clocks have since been provided with electro-motors switched on and off by hand, merely to replace men,

whereas they might also have replaced mechanism, improving the clocks as time-keepers and making them automatic.

There is not a turret clock in this country whose performance would not be improved by this treatment, but no surprise need be expressed that it is not done. In the case of Big Ben a proper reverence for the work of Lord Grimthorpe prompted the least possible alteration.

Such reconstruction work as I have outlined would be too venturesome an undertaking for the average provincial watch and clock maker, and none of our well-known firms of turret clock makers would standardise a new type of clock on these lines in view of the more direct and simple methods now available.

Here let me interpolate a description of an electric clock which defies classification, the Warren frequency meter, recently introduced in the U.S.A. under the name TELECHRON. It is neither a self-wound clock nor an electrical impulse dial, and is in a class by itself.

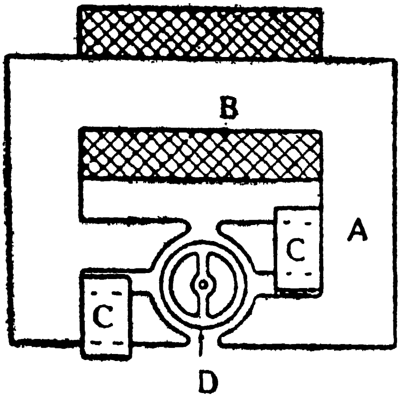
In an article in the *Electrical Times* of November, 1895, then known as *Lightning*, when Ferranti's bold introduction of alternating current had proved it to be the most economical method of generation and distribution of electricity in bulk, I forecasted the electric clock of the future as one driven by a small continuously running synchronous motor, geared down to make a mantelshelf clock, plugged into the consumer's A.C. supply.

It is exactly that which the Warren synchronous motor has achieved.

It is self-starting under load, reaching synchronous speed in a second or two. It measures only 2½ inches square, and the hands are usually geared to the rotor to suit a periodicity of 50 cycles per second. Rated at 4 watts the motor thus consumes some 30 or 40 B.O.T. units per annum.

Its construction is clearly shown in figs. 55 and 56

which are sectional drawings at right-angles to one another. The electro-magnet A with its winding B is provided with copper shading rings C which produce



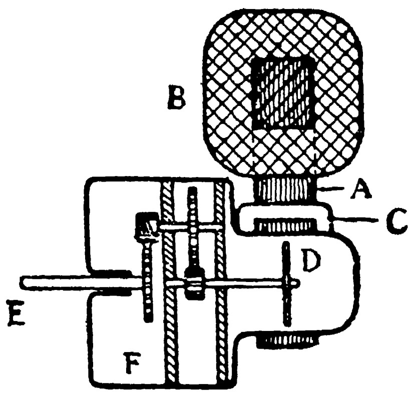


Fig. 55 and 56. Warren Synchronous Motor. It is only 2½ inches square and rotates in absolute synchronism, so that main spindle can be geared down to one revolution per second, forming an original Time Meter.

a rotating field. An iron armature D is situated within this field and rotates in absolute synchronism with the frequency of the supply owing to hysteretic drag. The

spindle carrying the disc is geared down so that the main spindle E revolves either once a minute or once a second, as desired. All the moving parts are enclosed in a dust-tight housing F containing oil in which the working parts are immersed.

Correspondents in the United States tell me that successful efforts are being made to keep the average frequency of their alternators in the generating stations at a constant speed. For the purpose, the Warren Company supply a good Graham dead-beat clock with seconds pendulum as a master in each generating station, and provide a seconds hand concentric with a Telechron seconds hand so that any lag or advance is revealed at once.

The advent of the "grid" and the linking up of our generating stations here under the Electricity Commission demands something better, and it is satisfactory to know that the London Power Co., Ltd., and other great bulk suppliers to the "grid" are combining the use of Telechròn synchronous motors with the Synchronome system of electric clocks, which will give the station engineers in the various areas exceptional facilities for keeping their alternators in synchronism, not only at any given moment, but true to time over a long period.

There is a great future before this method of wholesale distribution of uniform and fairly accurate time; how great and how soon it will arrive it is not easy to forecast; all we can say at present is that its star is in the ascendant. The tide of electrical engineering development in the generation and distribution of light and power has definitely turned in its favour. The use of alternating current is now becoming universal. Linking up of stations implies standardisation of periodicity which demands accurate synchronization and that in turn demands good time-keeping.

CHAPTER XIV

ELECTRICAL IMPULSE DIAL MOVEMENTS

Bain, Wheatstone, Shepherd, Garnier, Breguet, Reclûs, Perret, Morse, Joyce, Stockall, Hollins and Leake, Barr and Stroud, Magneta, Swift, and Prince.

THIS chapter brings us at last to the heart of our subject. By means of rigid condensation, the thirteen previous chapters have sufficed to cover the two first divisions of our threefold classification, viz., independent self-contained clocks and synchronisation, thus clearing the ground for the consideration of circuits of electrical impulse dials.

You will remember that we began with Alexander Bain in 1840, and we must go back to him for the origin of electric time service as we practice it to-day. In Chapter II the first five illustrations depict circuits of propelled dials operated by electrical impulses transmitted by the master pendulum. Thus the earliest electric clock patent in this or any country clearly outlined the proper method, and we are to-day in the main doing what Bain told us to do.

He failed to accomplish it himself because his electro-mechanical details were at fault. His transmitter was a seconds pendulum which made contact every swing and transmitted uni-directional impulses to dial movements as illustrated in fig. 57. A coil of wire, A, is suspended from two insulated springs between two permanent magnets, M, and consequently vibrated in accordance with the master pendulum, advancing the wheel D by means of the gathering click C and back-

stop B. The moving coil in a magnetic field is very efficient and needed to be, since in those pre -Leclanché days Bain relied upon an earth battery.

This was the first step-by-step electrical impulse dial movement in the history of electric clocks. It will be observed that there is nothing to prevent the wheel D from overshooting in a forward direction as a result of its momentum, but in other respects it is not very different from some in use to-day.

Shepherd's dial movements were designed on similar lines in 1850, but have only survived at Greenwich Observatory, where their peculiar periodicity of two seconds has become standardised, and a reliable impulse is now transmitted to them.

So we must blame Bain's contacts, their unreliability, their duration, and particularly their periodicity for the failure, rather than the movements themselves. Similarly, Wheatstone's dials—forerunners of our moving coil galvanometers—were condemned by the egregious attempt to operate them by induction derived from the master pendulum.

A more practical periodicity would be one impulse per minute, quite a sufficiently frequent movement of the minute hands to keep pace with the speed at which life was lived in the middle of the last century, and this was adopted in France, the Lille Railway Station being equipped by Paul Garnier with eighteen electrically propelled dials driven by minute impulses in 1855; Breguet also erected 72 in the streets of Lyons in the following year, and thereafter the French text books contain numerous examples of *compteurs électro-chronométriques* responding to minute impulses. To this class also belong the minute periodicity system of Victor Reclûs, of Paris, whose self-wound clock has already been noted in Chapter XII, the system of the late Col. David Perret, of Neuchatel, and many American systems, not inappropriately called "minute jumpers," such as those of Warner, Howard and Morse; while in England,

where half-minute periodicity has been generally adopted, some installations of this kind were erected by Joyce, Stockall, Hollins & Leake, and Barr & Stroud.

All these systems have—or had, for few have survived—the same essential features. A master clock

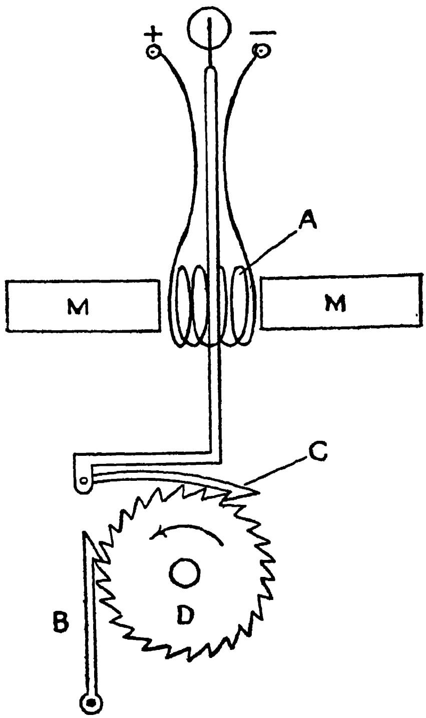


Fig. 57. The earliest Electrical Impulse Dial Movement. (Bain, 1843).

(usually an ordinary key-wound one, but in some cases self-wound) is fitted with a make-and-break contact operated at minute intervals by its wheel-work, in some such manner as that described in Class 1 (3) in Chapter XII. This contact (sometimes aided by a relay) transmits a uni-directional impulse through a circuit comprising a battery and a group of dials arranged either in series

or parallel. Each dial is provided with a movement whose function is to propel and lock a toothed wheel by means of the reciprocating armature of an electro-magnet every minute or every half-minute. The armature lever works against a spring or weight and simply hitches on a wheel one tooth at a time, and so progresses the hands much as Bain did in 1840.

In Bain's, fig. 57, the momentum of the hand might carry it more than one tooth, and it must never be forgotten that if a dial movement misses or overshoots only once in a million times it is condemned. Hence the introduction of the *cliquet d'arrêt*, or momentum stop E, illustrated in fig. 58, whereby the armature

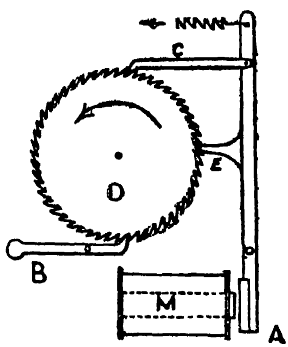


Fig. 58. The *cliquet d'arrêt* or Momentum Stop.

checks the progression of the wheel at the critical moment. The space at our disposal will not permit of a description of more than one variation of this type, so I select that of Reclûs as the best representative and illustrate it in fig. 59.

The magnet M lifts the armature A, which raises the counter-balanced pawl C into another tooth; meanwhile the arm E holds the backstop B in firm engagement with the wheel D. On the cessation of the current, the armature falls and the wheel is advanced one tooth.

Another obvious method is to propel the wheel half a tooth at a time by means of an anchor escapement, as shown in fig. 60, in which the pins P both *drive* and *lock*. The arms of the anchor are rigidly fixed to the armature A, but they may be detached and coupled by springs as in my Patent No. 1587 of 1893, or as in the

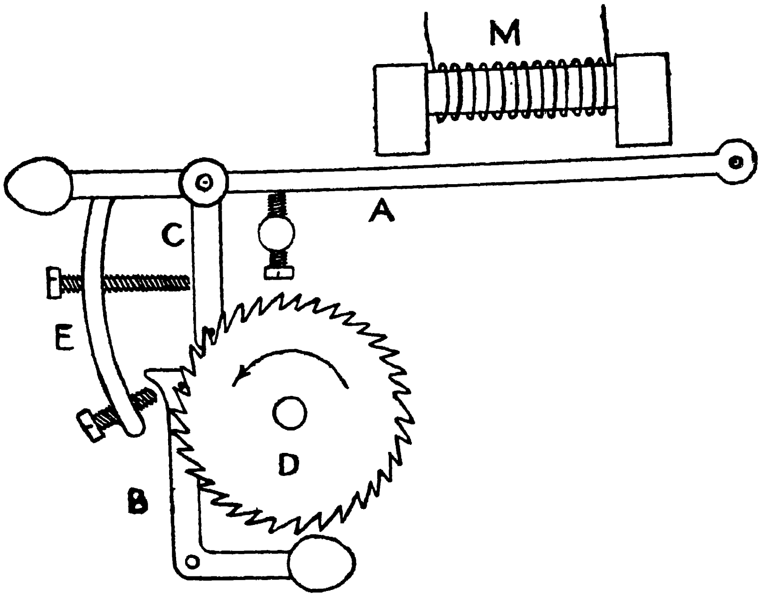


Fig. 59. Victor Reclûs, Paris, 1886.

Magneta Patent No. 15833 of 1901, from which fig. 61 is taken.

Or the wheel may carry the pins, and the arms of the ·or may be V-shaped, as in fig. 62, from H. B. atent of 1911. But of all the methods of oblique ·n I prefer that of Major C. E. Prince, who ·ngle pallet between the teeth of the two wheels, · in fig. 63, taken from his Patent No. 227499 The semi-circular pallet B mounted on the ·ocks between the teeth of the two wheels

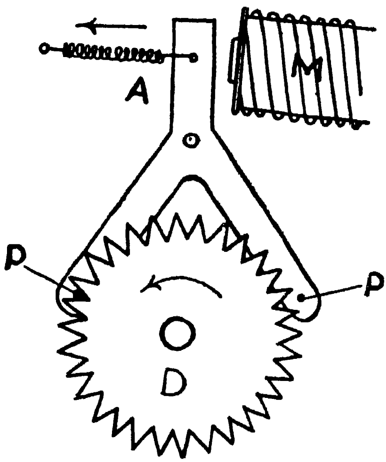


Fig. 60. Anchor Drive propelling Wheel half a tooth at a time.

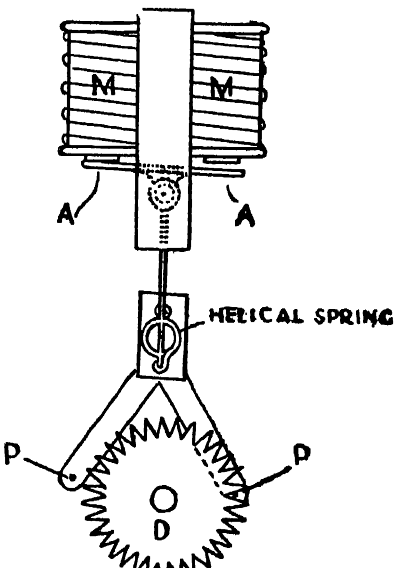


Fig. 61. Anchor Drive with Spring (Magneta, 1901).

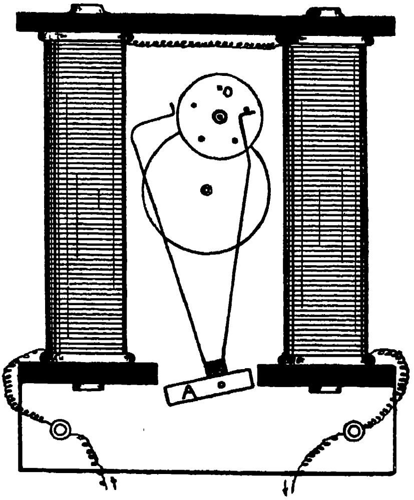


Fig. 62 Anchor Drive with Pins (Swift, 1911).

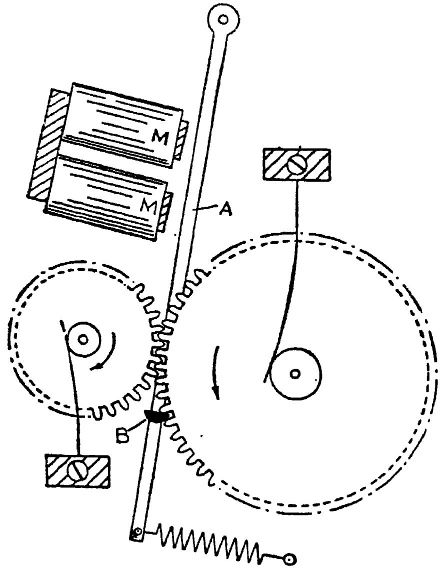


Fig. 63. Oblique Drive (Princeps, 1923).

geared together, one of which carries the minute hand whilst the other merely receives and passes on half a tooth's pitch of rotation.

All the dial movements in this family secure a satisfactory lock or are capable of doing so when well designed, made and adjusted, but they naturally lack the efficiency of the more direct propulsion, and are not used for heavy work. But, as a matter of fact, with the exception of the Magneta and Princeps, whose electrical impulses are derived in a totally different manner, none of the dial movements we have here reviewed have survived. Synchronous working of large circuits of electrical impulse dials has never been achieved by these systems.

I have never had any doubt as to the real cause of their failure. The conclusion I came to on technical grounds over thirty years ago is clearly confirmed by the history of the development of electric clocks on the Continent and in America throughout the latter half of the nineteenth century and since.

The difficulty lies not in the dial movements themselves, but in the nature of the electrical impulses transmitted to them. In other words, the contacts were at fault. The energy devoted to them was insufficient, being only what could be grudgingly spared from the time-keeping function of the master clock and they were lacking in precision in the make and break. Their duration was arbitrarily fixed, which usually meant that it was very much too long and added to battery worries already sufficiently acute because unrelieved by any compensatory action or battery warning. In every circuit of dials there will be some whose weights or springs are more delicately adjusted than others, and these will occasionally respond to partial impulses of a contact which is not always perfectly clean and decisive in its make and break.

In the welter of failure of all these systems during that fifty years, Bain's simple conception was lost or

abandoned. The direct method of one-wheel step-by-step dial propulsion was assumed to be impossible, and all sorts of comparatively complicated systems were evolved, some of which we shall discuss in the next chapter.

CHAPTER XV

ROTARY AND POLARISED DIAL MOVEMENTS

American, Belgian, G. B. Bowell, Hipp, Siemens and Halske, Aron, Grau-Wagner.

IN the last chapter we saw how Bain's original and simple conception of circuits of electrical impulse dials driven by uni-directional impulses, transmitted by a master clock, faded out after 50 or 60 years of trial and failure.

He transmitted his impulses every second, and, though all those who followed him adopted the much more practical periodicity of once a minute, no lasting success was achieved because the transmitting contacts were unreliable.

The realisation of this in 1895 led me to make a careful analysis of these systems, and I found in them, and in that fact, ample cause for the backward state of the science and practice of electrical time service which lagged far behind the progress of telegraphy, telephony, light and power, and the other electrical achievements of the nineteenth century.

The clockmaker who knew little of electricity put a pin on one of his gently moving wheels to engage a light spring, and made a poor contact, while the electrician, knowing little of horology, did the same with a stiffer spring, and stopped the clock or spoilt its timekeeping properties. That sort of thing had been going on for fifty years, and had ruined the reputation of electric clocks in this country; it ultimately killed all attempts at simple uni-directional systems, though some of them died hard; it drove us to the synchronisation of ordinary clocks by electro-mechanical devices;

it drove Paris to a pneumatic system and produced complicated methods in Germany and Switzerland in which the current was reversed at each impulse.

Nevertheless, efforts to produce dial movements that would keep in step in spite of inferior contacts still persisted, long after the real source of the trouble should have been recognised. This delayed the evolution of the science, not only here but abroad, and it is instructive to note how the difficulty was met in various countries.

In America, the tendency was to increase the mass and consequently the inertia of the moving parts, so that nothing less than the main impulse would operate them. This is not always successful, and it invariably implies waste of energy, yet the practice is in general use throughout the U.S.A. and has been so for fifty years. It may be fairly described as a brute-force method, and it is not surprising that the very roundabout system of synchronising the independent clocks of the Self-Winding Clock Company, of Brooklyn, and more recently the Sangamo system of synchronised self-wound clocks find greater favour and that both are now giving place to the "TELECHRON," described in Chapter XIII.

In Belgium, La Precision Cie. exploited the invention of Van der Plancke, who employed an armature shaped like a hammer, lettered A in fig. 64, adapted to hit the pin P on the weighted flywheel D, thereby kicking it round. The armature A falls back from the magnet in time for its hammer head to receive the pin P^1 so that the flywheel may generally be relied upon to take up its proper position ready to receive the next hammer blow resulting from the next half-minute impulse. This implies extra gearing from one revolution to 1/120th part of a revolution in order to advance the minute hand one half of a minute. The Electrical Time Recording Co., Ltd., made a serious attempt to introduce it into England in 1893, and erected a couple of dozen

installations during the next few years, but the contact being of the type which I condemned in Chapter XII, not one of these installations survived.

It is fairly obvious that a dial movement which has

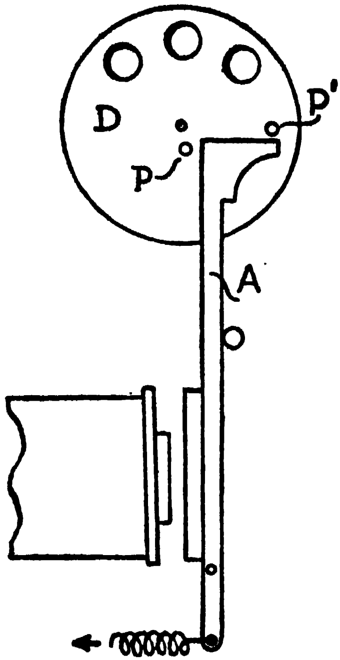


Fig. 64. Electrical Impulse Movement of Van der Plancke, Belgium.

to perform a whole, or even a half, revolution of a fly-wheel or an armature in response to a uni-directional impulse is more capable of resisting the temptation to respond to the unauthorised stutterings and preliminary sparks of a contact which lacks precision in the make and break, than a dial movement which has only to pick up one tooth. But these are only attempts to palliate the evil; they do not strike at the root cause.

A considerable measure of success was achieved by the Silent Electric Clock Co., with a rotary dial

movement of Mr. G. B. Bowell, illustrated in fig. 65, taken from his Patent No. 20496 of 1909.

The rotating armature has four arms (only two of

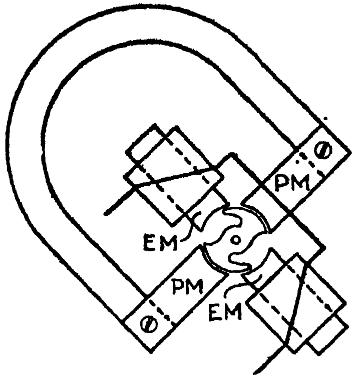


Fig. 65. Electrical Impulse Dial of Mr. G. B. Bowell.

which are shown) surrounded by four poles, two of which, P, M, belong to a permanent magnet and two, E, M, to an electro-magnet. Half-minute impulses passing through the electro-magnet rotate the armature one-fourth of a revolution, and a little more by impetus, after which the permanent magnet does the rest.

The rotary motion of an armature is essentially more silent than step-by-step propulsion, particularly when the damping is magnetic, and silence was the avowed object of this construction. But reliability must always be the first consideration, and the nature of the contact contributed to its success. Fig. 66 illustrates it in principle and shows how a Hipp pendulum P with its butterfly escapement E charges into the contact springs B, D, one tooth of the 15T wheel being cut lower than the rest so as to enable the driving click C to engage with the projection F on the spring B at the end of every 30th swing. Though this master clock comes under our condemned classification, since all the energy is robbed from the pendulum, and that at the

end of its swing, its contact is much better than its predecessors because it has the advantages of consider-

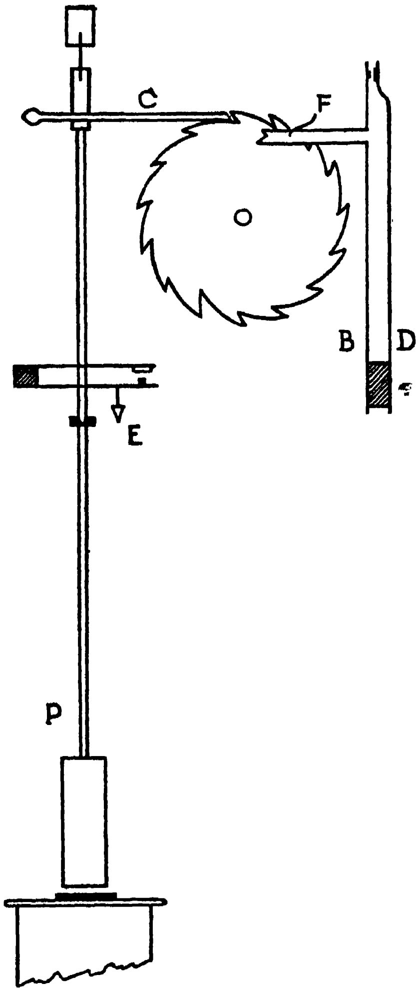


Fig. 66. Master Clock of Mr. G. B. Bowell.

able motion, considerable power, and an equable approach at the speed of the moving pendulum.

The energy taken out of the pendulum is quickly and automatically restored by the Hipp butterfly escapement, but it must be observed that variation of arc aggravates the evils of interference with the pendulum at the end of its swing. In the Hipp driven pendulum the periodicity of the restoration bears no fixed relationship to the half-minute contact-making function, consequently the interference is a variable quantity.

On the Continent, the trying-out and turning down of uni-directional step-by-step dial movements was

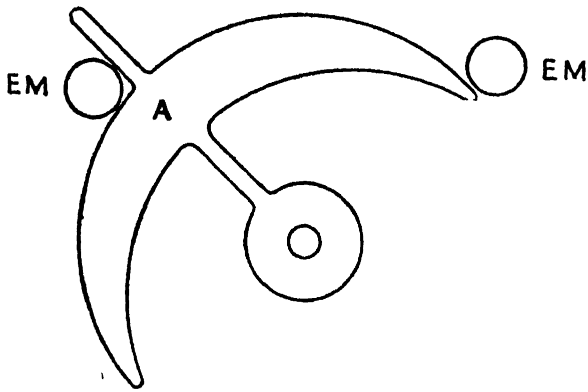


Fig. 67. Polarised Dial Movement of Hipp.

much more rapid. So far as I have been able to ascertain, Hipp was the first to realise the futility of the contacts of his day and to introduce a radically different method which was destined to establish what we may conveniently call Continental practice in electric clocks.

He reversed the polarity of his battery every minute, or, in other words, he made his master clock transmit an impulse first in one direction and then in the opposite direction, and employed polarised dial movements which rocked the armature to the right at one minute and to the left at the next. Every impulse may therefore consist of a whole group of untidy splashes without putting one of the polarised movements out of step.

Fig. 67 is a plan view of the pivoted armature A and the poles of the electro-magnet between which it rocks. The armature A being permanently magnetised, then according to the direction of the current passing through the electro-magnet the pole on the right will attract whilst the left-hand one repels at one minute; the left attracts and the right repels at the next minute. The oscillatory motion which results is converted into a rotary one by a verge escapement.

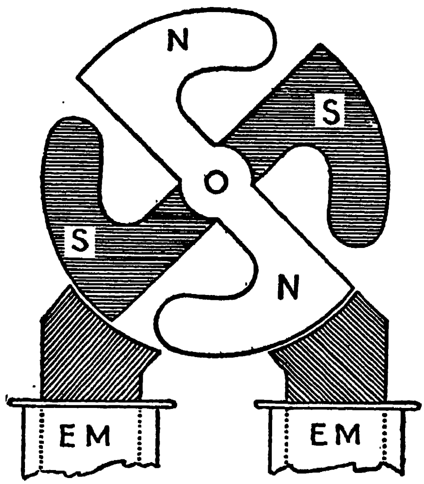


Fig. 68. Rotary Dial Movement of Grau-Wagner.

The systems of Siemens and Halske, and that of Dr. Aron, both of Berlin, are of this class, whilst those of Grau and Wagner, of Wiesbaden, also employ polarised movements, but their armatures are rotary instead of oscillating. Fig. 68 shows how this is done, it being understood that the double cams constituting the armature are associated with the opposite poles of a strong permanent magnet, as lettered N and S. Hence successive impulses passing through the electro-magnets alternately in opposite directions will cause rotation in steps. The master clock is a key-wound one,

with a separate power train for making contact which reverses the polarity of each impulse. The dial movement may be described as an alternating current motor driven one quarter of a revolution every minute.

Until the advent of the Magneta system, described in Chapter III, this method of reversing the current at each minute held the field in Switzerland and Germany, and it is still in use. In fact, it has outlived the stage of the proprietary article protected by patents, and, in one form or another, is manufactured by such firms as Favarger, of Neuchatel; C. Theod. Wagner, of Weisbaden; Hoerz, of Ulm; Weule, of Bockenem; and Siemens & Halske, of Berlin. A few installations have found their way into England, but polarised working has never taken root here, for the sufficient reason that a standard British practice has been evolved during the last thirty years, equally distinctive but far superior.

Take one point alone—the efficiency of these systems in so far as it bears upon the life and management of the battery. Rotary armatures with their oblique electromagnetic pull can never be as efficient as the direct drive of a reciprocating armature. In addition to this, the duration of the minute impulses in all the above systems is usually much too long, being a matter of arbitrary adjustment based upon a purely human estimate of the time required to energise the dial movements. It varies in different systems from 0·1 sec. to 1 sec. Recollecting that there are over half a million minutes in a year, this involves a contact time-factor of anything from 15 to 150 hours per annum; and there is nothing more extraordinary in the history of electric clocks than the neglect of this consideration and the waste of electrical energy resulting from contacts whose duration is frequently ten times as long as is actually required to overcome the electrical and mechanical inertia of the dial movements.

CHAPTER XVI

THE SYNCHRONOME

Electrical Impulse Dial Movement

HAVING satisfied myself as to the main cause of the failure of simple uni-directional electrical impulse dials, I re-introduced them in 1897 when I had a switch competent to operate them. To convert electrical impulses into rotary motion, most inventors began with a rocking lever carrying a driving pawl at a tangent to a ratchet wheel, as in fig. 69. In this and all the other illustrations in this chapter, it will be

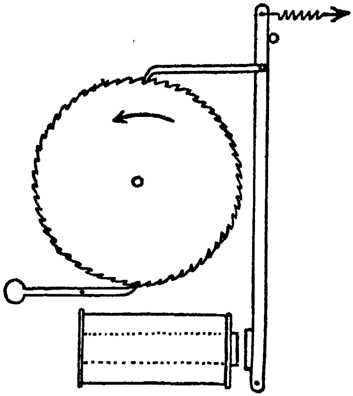


Fig. 69

understood that the arbor of the main wheel carries the minute hand, the motion work and hour hand not being shown.

The faults are obvious. The wheel is altogether unlocked and the momentum of the minute hand will cause it to overshoot. A click was added entering the

teeth of the wheel along a radial. This was the *cliquet d'arrêt* of the *compteur électro-chronométrique* of the French textbooks, illustrated in fig. 70. This prevented overshooting, but left the wheel normally unlocked. However, that was easily set right by reversing the action

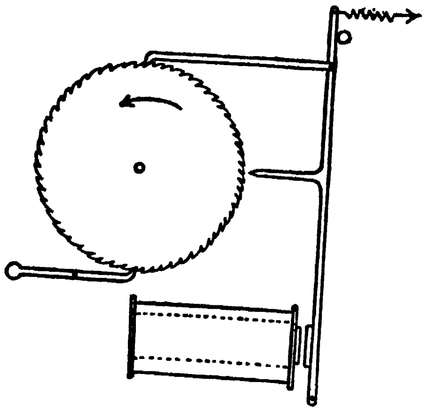


Fig. 70

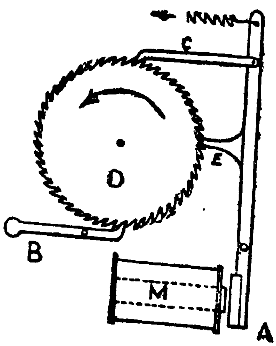


Fig. 71

of the spring and magnet as shown in fig. 58 of Chapter XIV, and reproduced here in fig. 71.

This design demanded great accuracy of wheel cutting and mounting and fine pivoting of the levers. Each of the three clicks had to operate in their teeth

in perfect phase, and when they were spread all round the wheel the slightest eccentricity or other fault would cause trouble. There was sufficient reason in this alone for the adoption of the Continental fashion of minute periodicity since a construction which was difficult with a wheel of 60 teeth would become impossible with the small tooth pitch involved in 120 teeth, but minutes were good enough to keep pace with life as lived in the middle of the last century.

The invention of the Synchronome switch in 1895 introduced a satisfactory electrical contact which could

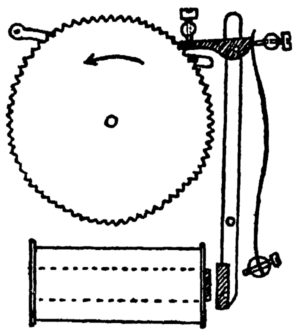


Fig. 72

be relied upon to transmit a uni-directional impulse perfectly clean in the make and break, and made it worth while to study the problem of step-by-step propulsion as applied to the hands of clocks. The philosopher's valuation of a man's wealth being estimated by the things he can do without, and this being even more true in the field of mechanics, it behoved us to consider how one part can be made to serve two purposes.

The result of the effort is recorded in Patent No. 7868 of 1897, from which I reproduce fig. 72, which shows how the functions of the *cliquet d'arrêt* are performed by banking the nose of the driving click against

a fixed stop. The principles involved are worth describing, since they form the basis of all types of electrical impulse dial movements now in general use, which directly propel the hands of a clock by picking up one tooth at a time by means of a reciprocating lever.

It will be observed that each tooth of the main wheel forms a right angled isosceles triangle, the hypotenuse of which forms a tangent to the wheel. The free end of the pawl is also rectangular and normally rests upon a tooth in line with its face, *i.e.*, at an angle of 135 degrees with the radius at this point, and when driven forward it propels the wheel and rising with it finally meets with a fixed stop which effectually prevents the click or the wheel from proceeding further, while a backstop click prevents the wheel from returning. By arranging the parts in this manner, it will be seen that the forward motion of the driving click in the direction of its length is equal to the rise of its free end and that while the click normally locks the wheel it is nevertheless free to slide straight off the dead surface of the tooth without being lifted when the next impulse is sent out from the controlling clock.

Admitting that the most efficient driving angle is the tangent, *i.e.*, with the direction of motion of the driving pawl at right angles to the radial, and that the best place to get hold of a wheel to secure it against motion is by a stop approaching it along the radial itself, if it is desired to combine both functions by the simple expedient of providing a momentum stop over the nose of the driving click, then the place to get hold of the wheel is midway between the two.

If the fixed stop is placed above the nose of the driving pawl when it is driving at a tangent as in figs. 69, 70 and 71, then the slightest eccentricity of the wheel, causing variations in the length of the radial, will result in the click binding between the circumference and the fixed stop at some points or will allow excessive free play between the backward and forward locking.

But if you let the driving pawl approach the wheel at an angle of 135 degrees to the radius, then its point will rise vertically exactly the same distance that it advances horizontally whatever the shape of the teeth may be. Square teeth are thus indicated, and if the upper and lower surfaces of the pawl are parallel, or slightly tapered towards the nose, then it is always free to be withdrawn by an electro-magnetic impulse of short duration, defeating the slightest tendency to jamb.

And the ill effects of eccentricity, irregular wheel-cutting and other imperfections largely disappear, since the only thing concerned in the precise position

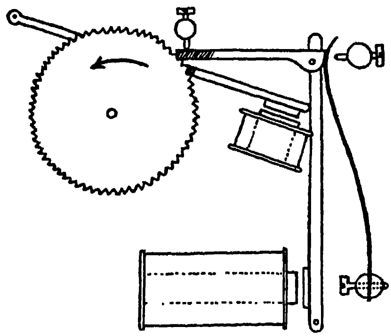


Fig. 73

taken up by the wheel, is the backstop click—a near neighbour—only three or four teeth away.

Thus the work of propulsion and locking is concentrated upon a small group of teeth which take up their own position under the noses of the two clicks concerned.

The wheel is normally locked, but its freedom to move forward whilst the driving click is withdrawn must not be permitted if the hands are exposed to the weather. In my 1897 Patent, I provided for the addition of a small supplementary electro-magnet (in series with the propelling magnet) to hold down the back-

stop click during the withdrawal of the driving pawl as shown in fig. 73, but in 1909 I produced its mechanical equivalent, which was better and simpler. A notch is cut in the back of the armature lever, and the back-stop lever is extended to carry a square-faced steel pin to hold the wheel at that moment, the only time when

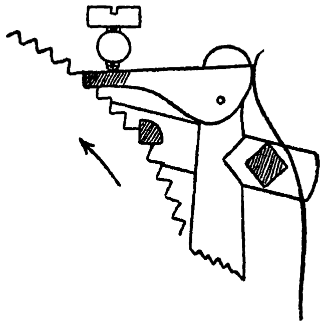


Fig. 74

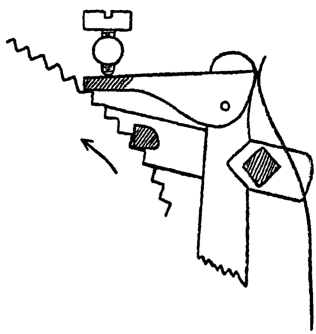


Fig. 75

the propelling operation could leave it unlocked. The series of illustrations, figs. 74, 75, 76, 77, serves to show how the wheel is locked throughout the whole cycle of the driving operation. It is, in fact, a perfect escapement which can only pass one tooth at a time.

Electrical impulse dial movements on this system are designed for quick action. We shall see later on,

in Chapter XIX, how the contact in the master clock is prolonged until its duration is sufficient to overcome the electrical inertia or self-induction of all the electro-magnets in series with it. The mechanical inertia of the armatures in the dial movements is designed

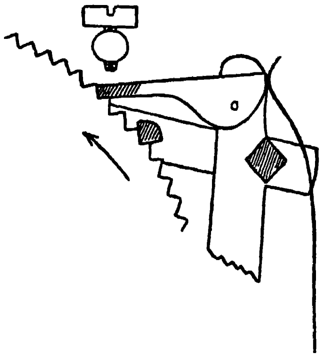


Fig. 76

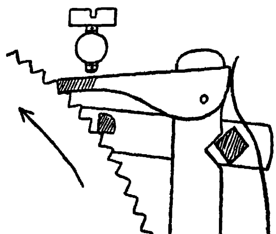


Fig. 77

to be less than the electrical inertia. Hence the armature levers are light in weight, are disposed vertically on their pivots and balanced so that the electro-magnetic pull is against a spring and not a weight.

In order to demonstrate the ability of movements of this design to respond to electrical impulses of very short duration, I once set up a dozen specially adjusted to work in series on an alternating electric light supply

service of 100 v. and 50 cycles. It was satisfactory to see them keep in perfect step at the speed of 100 impulses per second.

The merit of simplicity and the advantages which follow from the use of one member to perform two duties are well illustrated by the ease with which the wheel is freed from its driving and locking clicks. In the design shown, the underside of the driving pawl is so shaped that the raising of the backstop click retires both from the wheel, providing facility for setting to time and zeroising.

Pamphleteers championing other and less direct methods have indulged in much wild talk in condemnation of the picking up of one tooth at a time by steel claws, alleging wear, shock, and noise. A lifetime's experience has, however, shown that a hard steel click and a 120T brass wheel will stand up to it, whilst the momentum stop takes the shock. Silence in action can be secured by the simple expedient of raising the pivot and giving the magnet long curved poles over which the armature floats between soft bankings. It can be damped sufficiently for all ordinary purposes, and its simplicity, efficiency, and directness are overwhelming considerations, which account for the fact that it is doing, and will continue to do, nine-tenths of the propulsion of electrical impulse dials in this country and wherever impulses derived from a switch of the Synchronome type are available.

Reverting to the question of periodicity, impulses once a minute are still the custom on the Continent and in America, where they are called "minute jumpers."

One of the merits of step-by-step propulsion is dead-beat action of the hands and the elimination of the back-lash, which is inevitable when gearing is employed. Practical politics suggested the smallest periodicity and tooth pitch, *i.e.*, the largest number of wheel teeth which could be economically manufactured in a movement without gearing.

The movement above described can conveniently deal with 120 teeth; with 240 teeth necessary for quarter minutes, the tooth pitch would be too small, and 60 unnecessarily large. Such were the material considerations on which half-minute periodicity was established, as standard British practice, between 1895 and 1905, by the Synchronome system when it was ploughing its lonely furrows as the pioneer of electric time service.

How often in horology have inventors builded better than they knew! A famous example is the frictional compensation of arc in Graham's dead beat escapement, a merit of which it seems quite certain he was unaware.

"Nature never did desert the heart that loved her," and it would seem that she holds in reserve unexpected rewards for those who strive to build on scientific principles.

The Synchronome switch contained more virtues than its inventor wot of, and with regard to this electrical impulse dial movement, it has far surpassed the hopes of its parents. Its effect upon turret clock making has been revolutionary, since it enables sufficient power to drive large clock hands in the open, to be concentrated in a small space. This power can now be placed on the very spot where it is wanted, viz., on the back-centre of the dial where it is concealed by the bosses of the hands, thus leaving the clock chamber vacant and available for illumination, and enabling the centre panels (carrying movement and hands) to be detached and withdrawn inwards as described in Patent No. 239,017.

CHAPTER XVII

HALF MINUTE IMPULSE PENDULUMS

Campiche, Lowne, Palmer

IN the last three chapters we have surveyed a large variety of electrical impulse dial movements, and we have seen that almost the only survivals have been the polarised mechanisms demanded by inferior contacts, and the type described in Chapter XVI.

To continue the attempt to trace the evolution of the successful systems of electric time service which we enjoy to-day, and to understand why we are able to use this most simple type of electrical impulse dial movement, we must now step back a little and consider original methods of propelling a pendulum as distinct from ordinary clock escapements.

I use the word "attempt" advisedly, because when every inventor reveals his ignorance of the work of his predecessors, the evolution is confused and is in any case a very slow process. The causes of failure were not recognised, and were repeated *ad nauseam*. Useful features seem to have arrived by chance, since the inventors of the systems in which they appear invariably fail to mention their merits, whilst they often eulogise commonplace features, imagining them to be original.

A curious example of this is the origin of the idea of impelling the controlling pendulum at long intervals, every half-minute or so, instead of using the ordinary escapement which gives impulse to the pendulum at every beat.

The real merit of the idea was neither understood nor recognised at the time even by the inventors themselves, as is evident from their patent specifications;

yet the advantages which flow from occasional impulse are so great that they were destined to play a large part in the recovery for Great Britain of the world's record for accurate time measurement in 1923.

Hipp's clock, invented in 1842, or earlier, and described in Chapter IX, ought to have taught the merit of occasional impulses, but it did not. That intrinsic vice of all escapements, the long and almost continuous interference with the freedom of the pen-

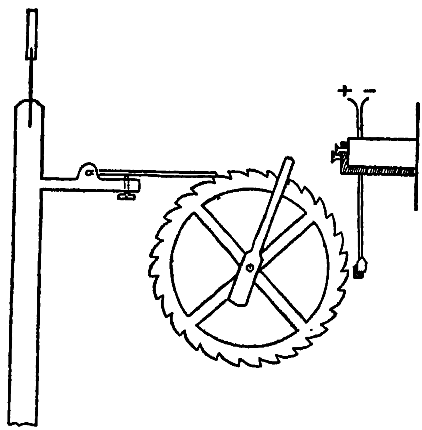


Fig. 78. Campiche's Count-Wheel and Contact.

dulum, was unthought of, was never mentioned in text-books, and was accepted as inevitable if considered at all.

Inventors looking at a Hipp clock with a philosophic mind should have been fired with the ambition to liberate clockmakers from the thraldom of escapements which had fastened themselves on their shoulders like the Old Man of the Sea for 200 years, but that can hardly have been the motive of Campiche, Lowne, Palmer and others who impelled their pendulums every half-minute, since they failed to realise the merit of reduced interference and the increased energy available for contact-making purposes.

But it would ill become me to belittle their contribution to the development of electric time service, and the fact remains that they were the first to propel the pendulums of their master clocks by half-minute impulses.

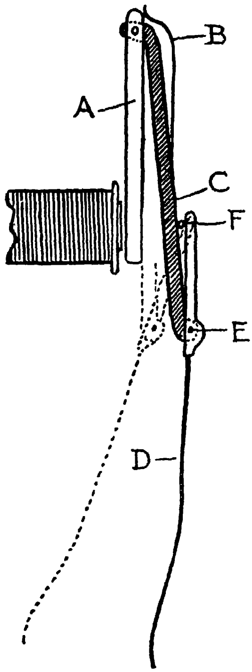


Fig. 79. Campiche's Pendulum Drive.

The Campiche Patents were taken out in 1893, 1894, and 1899, by various members of the family, all of Cairo.

Fig. 78 shows their count wheel and contact. A pivoted finger on the pendulum propels the count-wheel tooth by tooth, and, at the completion of each revolution, a vane attached to its arbor is embraced by two contact springs shown in perspective on the right. Fig. 79 shows how the impulse is imparted to the

pendulum. A short movement of the armature A stores energy in the spring B, which causes lever C to follow it at leisure, and to impart a long and gentle impulse

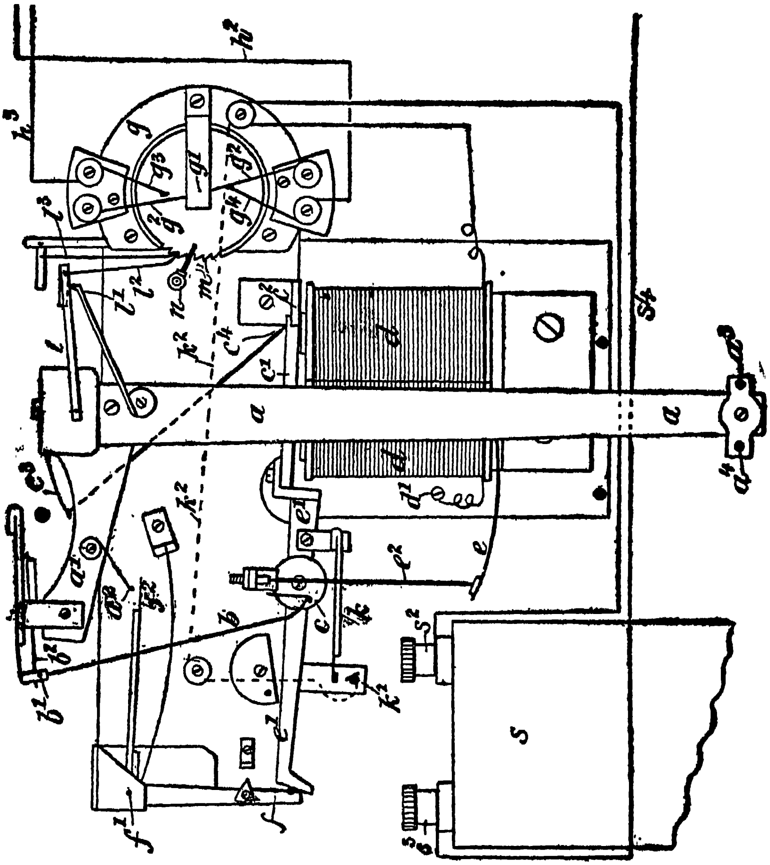


Fig. 80. Lowne's Half-minute Transmitter.

to the pendulum through the medium of a long and springy finger rod D, centred at E and tilted against the stop F into the position shown by the dotted lines.

Individually, these devices are without merit. It

is impossible to commend a contact deriving all its energy from the pendulum, and that at the end of its swing; and the method of imparting an impulse to the pendulum is frankly bad, but the originality lies in the use of a count-wheel, and in the combination in one circuit of the pendulum propelling magnet and electrical impulse dial movements. An attempt by a well-known West End clockmaker to introduce this system into London failed in 1911.

The time transmitter of Lowne, of Catford, is shown in fig. 80, taken from his Patent No. 25374, of 1901. The pivoted crutch *a* (the pins at the bottom of which, a^3, a^4, embrace the pendulum rod) has an extension at the top which carries the escapement rod *b*. The armature c^1 is held up normally off the poles of the magnet by the flat steel spring *e* through the medium of the rod e^2. A pivoted rectangular catch *f* is centred at f^1, and a gathering click l^2 pivoted on an arm *l* revolves wheel *m* once a minute, operating contacts g^2, ^{3}, ^{4}, by means of a cam g^1 (not shown). The magnet *d* is energised once every half-minute, and power is stored in spring *e*. The armature c^1, when it is thus pulled down, is caught by *f*, which holds it there until the pendulum, on its next swing to the right, releases it and allows the spring *e* to discharge itself into the pendulum through the medium of the escapement rod *b*.

The invention also includes a fly-wheel linked to the armature c^1 to slow its motion in order to make sure that the circuit remains closed until the most sluggish dial has operated; there are also contacts in the dial movements to enable them to cut themselves out of circuit when they have operated.

Here again the contact derives all its energy from the pendulum at the end of its swing, and I attribute such success as has been achieved by this system mainly to good workmanship and to the fact that interferences due to impulse and contact take place only once every half-minute.

Fig. 81 is taken from Patent No. 10541, of 1902, of Mr. W. E. Palmer, and the reader will be struck by its general resemblance to the master clocks of to-day. It is clearly a progressive step, though the contact and impulse still leave much to be desired.

It will be observed that when the count-wheel has unlatched the gravity arm A, this latter, in falling, impels the pendulum by the impulse pin B. A flat steel spring

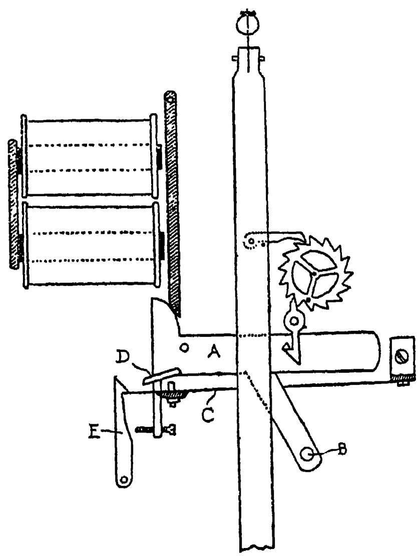


Fig. 81. Palmer's Half-minute Transmitter.

C is held by catch E, and the last thing A does at the end of its fall is to unlatch this spring C, which snaps into contact with the inclined plate D. The magnet then lifts the gravity arm A, and the latter, in rising, reinforces the contact by the motion of the inclined plate D in replacing the nose of spring C under its catch E. Thus the energy for contact-making comes from the gravity arm and is not taken out of the pendulum.

In this respect it is analogous to the intermediary stage in self-winding clocks, dealt with in Chapter XII.

The impulsing of the pendulum is open to the same objections as Shepherd's clock, described in Chapter X. To accomplish the release at exactly the right moment in conditions of varying arc was found to be practically impossible at Greenwich, and it is obvious that shock and vibration of the pendulum must result unless this is achieved.

It is easy for us to see now how Palmer just missed doing the right thing. He uses *some* of the energy of his electro-magnet for contact purposes, but not all. Had he applied the 1895 Synchronome Patent to it he would have used all and created a fine switch. But it must always be remembered to his credit that he did not rob his pendulum for contact-making energy, and that was equal to Froment's forgotten contribution to the science, plus the merit of half-minute periodicity.

These three systems, Campiche, Lowne and Palmer, were the pioneers of an idea which, when properly applied, ultimately became valuable and which therefore ranks as a definite contribution to the science of electric time service.

The idea may be defined as the use of a count-wheel, the giving of the impulse to the pendulum once only in each minute or half-minute, and the control of a group of electrical impulse dials in the same circuit.

CHAPTER XVIII

THE TRANSMISSION OF ENERGY THROUGH THE SURFACES OF THE CONTACT

IN the last chapter we described the master clocks of three systems of electrical impulse dials, Campiche, Lowne and Palmer. The important and original feature of these controlling pendulums or electric time transmitters was the fact that their pendulums received one impulse of considerable power every half-minute instead of 30 small impulses, one each second. In the case of the third, Palmer, this impulse was given by a gravity lever which was associated with the function of making the contact.

I propose to devote this chapter to the consideration of this feature, and its importance in the development of electric time service, particularly its bearing upon the contact.

You will remember that in reviewing self-wound clocks in Chapter XII the natural sequence of evolution led us to the Synchronome remontoire of 1895. In that, the gravity lever was concerned in the act of contact-making, and it operated every 30 seconds, but it impelled the pendulum through the medium of a Graham dead-beat escapement, falling a little way every second, whilst Palmer went further and applied his gravity lever direct upon the pendulum with one considerable fall every half-minute.

This takes us back to the consideration of gravity escapements, from which we had to break away at the end of Chapter XI, after describing Shepherd and Froment. The great feature of Froment was that his gravity lever was not only associated with the contact, but actually formed part of it, and that the impulse

energy was transmitted through its surfaces, but its fault was the long duration of the contact, which not only spelt electrical inefficiency, but so completely lost, by diffusion, the merit of energy transmission that its underlying virtue—a great and valuable principle—was never discovered, even by its inventor.

Now the above-mentioned Synchronome remontoire of 1895 (fig. 52) Chapter XII, had already overcome both those faults by concentrating the energy into a contact of short duration, with the additional advantage of a momentum break, and an attempt was made to put it in the form of a gravity escapement, without the loss of these advantages. The effort is illustrated in fig. 82, taken from my Patent No. 7868, of 1897. By means of the roller O the pendulum helps itself to the services of gravity levers P and when each, in turn, has delivered its impulse, it meets with the armature C and is thrown up on its catch by its electro-magnet.

It will be observed that the levers P approach the armature C at the speed of the moving pendulum. They "sail" into contact at a speed which can be selected and set. None of the other merits are lost. Thus, contact having been established, the first effect of the passing of current is to reinforce the contact. Its duration is dependent upon two things, (1) the moment of inertia of the two moving members of the switch, the driving and the driven (mainly proportional to their mass which we vulgarly call weight), and (2) the time-constant of the circuit which is mainly dependent upon the self-induction of the electrical instruments in series with it. Better than Froment in its reduced duration of contact, now concentrated into about the one-twentieth part of a second, it is worse than Froment in that the pendulum has to unlock its own maintenance; better than the 1895 Synchronome in the gravity arm's approach to its contact being continuous, but only a thirtieth part as good as a switch if the gravity arm is only one thirtieth part of the weight.

That was the state of development arrived at when Campiche, Lowne and Palmer introduced the count-wheel to enable the pendulum to perform the contact-

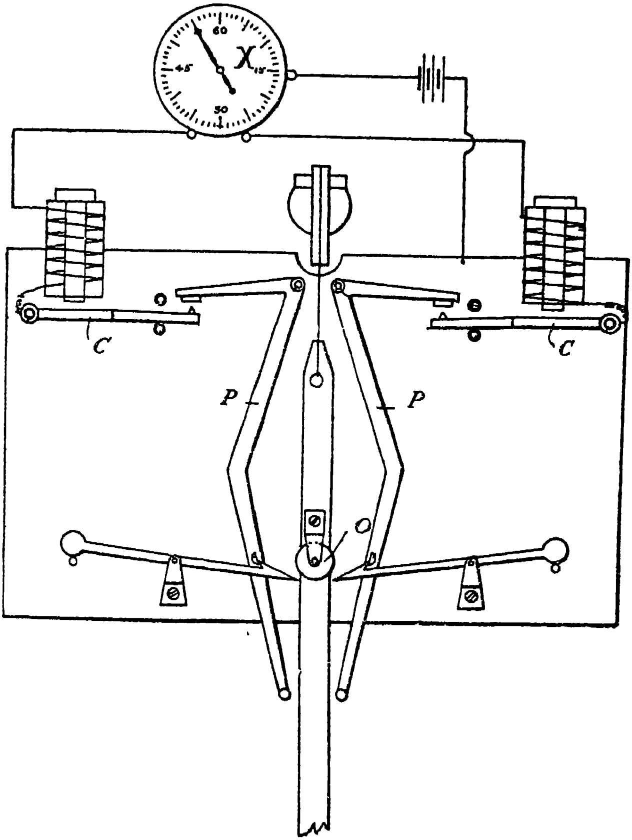


Fig. 82. Synchronome Gravity Escapement with Impulse and Contact every second.

making function and to receive its impulse every half-minute.

Here, then, was an obvious and simple piece of constructive building to be done with materials ready to hand.

I had been seeking for more energy for contact-making purposes, and I obtained it by leaving the Synchronome gravity arm hung up on a catch, employing the pendulum to count out 30 beats and to release it once every minute or half-minute. That was done in my Patent No. 6066, of 1905, from which fig. 83 is taken.

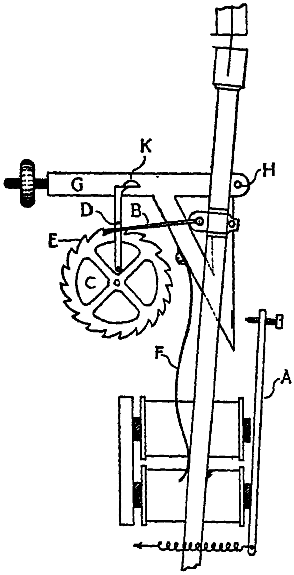


Fig. 83. Synchronome Gravity Escapement with Impulse and Contact every 30 seconds.

The lever G centred at H is supported on the catch K. The little lever B carried on the pendulum propels the wheel C tooth by tooth, normally passing underneath the stop D until it rides at a higher level on the shallow tooth, E, when it engages the stop and releases the catch K. The gravity lever G then falls and imparts an impulse to the pendulum through the feather-spring F. The spring-drive is open to many objections and has never justified itself either in the hands of Campiche

or in mine. I was groping, perhaps somewhat blindly, for a means of beginning and finishing the impulse with extreme gentleness, which I did not realise until three years later.

The energy which it is necessary to put into a seconds pendulum of normal weight, swinging freely in atmosphere through an arc of, say, three degrees, is of the order of 5 ft.-lbs. or 69,100 centimetre-grammes per week, though the storage in the form of raised weights in an eight-day clock is often double that figure. As there are 10,080 minutes or 604,800 seconds in a week, we may express this as 6·85 c.g. per minute, or ·114 c.g. per second, and, if we take one centimetre as a convenient distance for a gravity arm to fall, its weight must be either 6·85 g. for minute operation, or ·114 g. for seconds operation.

Shall it be little and often or an occasional square meal? Passing in rapid review all the applications of electricity to horology we have described, you will be struck by the fact that little and often has been the rule throughout.

It is difficult to state definite reasons for this, but two conservative influences seem to have worked unconsciously in the minds of inventors.

In the earliest days of the pendulum, from its conception by Galileo, or its invention by Huyghens, the impulse was always given at every vibration or semi-vibration. The very word escapement assumed it, it was sanctified by custom, and no one thought of doing anything else.

And, when you consider the beginnings of electricity, you will find that electro-magnetism was assumed to be capable of doing only little jobs. As an instance of this, let me remind you of the dial at the gate of Greenwich Observatory, which was provided with a magnet as big as a modern 1 h.p. motor to propel a 6 in. seconds hand. Electricity was then distrusted.

Remember that remark of Lord Grimthorpe which

I quoted in Chapter X, "And anyone who sets to work to invent electrical clocks must start with this axiom, that every now and then the electricity will fail to lift anything, however small."

To provide ·114 c.g. is not asking too much from electricity, whether we call upon it to raise a weight of one-twentieth of an ounce a distance of a quarter of an inch, which in falling pushes the pendulum, or whether we use it to pull the bob by electro-magnetic attraction.

Even when electricity was better understood, it being still taken for granted that all the energy required for the purpose of making electric contact had to be taken from the pendulum, it was obviously desirable to use as little current as possible.

Hence such efforts as those of Lord Kelvin, Sir David Gill (whose use of Crooke's tubes I mentioned in Chapter X), and many another great scientist to make reliable contacts with the minimum of energy, all of which were doomed to failure.

Their unhappy experience should serve as a warning to the present generation, *but it will not.* In such matters I am a pessimist; the inventor will continue to blunder on, neglecting the lessons which past failures should teach him. At this moment, there are still many who are wasting time and money in attempting to operate pendulums or count their vibrations from selenium cells and thermionic valves.

The greatest inventions are those which turn an evil into a blessing, which take an antagonistic force and set it to work in your favour, which convert an enemy into a friend.

From the moment it was realised that the energy put into the pendulum could be transmitted through the surfaces of the electrical contact, the whole aspect of the matter was changed. I welcomed the work to be done, since the heavier the gravity arm and the further it had to be lifted, then the better the contact would

be, and I have been surprised at the failure of other inventors to appreciate the complete reversal of policy involved. Some have made use of the device without acknowledgment, apparently unconscious of the benefits it conferred and failing to take full advantage of it.

You cannot get enough of it; it is worth its weight in gold, since it ensures the proper increment of current throughout the whole series circuit necessary to operate the electrical impulse dials. Not until the current has grown to that value which will generate sufficient electro-magnetic energy to raise this weight will the switch operate, and all this time more and more energy is expended upon the pressing together of the two surfaces of the contact. Ultimately, its momentum comes into play and ensures a clean and rapid break.

In the case of the Synchronome free pendulum, which swings *in vacuo*, the energy is only about one-fifth of that required in atmosphere, and, as it has nothing to do but to flex its spring, this energy is provided by a lever weighing 0·43 gramme and falling 2 mm.

Imagine *one-thirtieth part* of that energy, such as would be required if impulse was imparted to the pendulum every second! What good as a switch would be a lever weighing one fifteen-hundredth part of an ounce and falling less than one-eighth of an inch? Even in its half-minute form I had to condemn it as being insufficient to serve as a reliable switch, and thereby drove Mr. Shortt to use it to release a heavier lever. His account of the disassociation of the two functions—impulsing and switching—and the provision of two levers, one for each purpose, was the subject of a recent lecture before the British Horological Institute and is described in chapter XXIV.

Absolute reliability and continuous running is the first necessity of a precision clock for observatory purposes. Astronomers could not be bothered with an electric clock which was liable to stop or which needed

attention. This is more than ever true, now that (quoting Dr. Jackson, of Greenwich) "it seems that we are getting to the stage in which we can compare the lengths of two successive years to one second of time."

The secret of that reliability is the Synchronome switch and its first main principle, the transmission of energy through the surfaces of the contact, a principle clearly enunciated in my lectures and patents from 1895 onwards, yet absolutely ignored by the horological schools, journals, and text-books of the rest of the civilised world. It has never been understood or appreciated in France, Switzerland, Germany or the United States, nor mentioned in their technical press, but it is their loss, since by its use the supremacy of British practice has been established.

CHAPTER XIX

THE MOMENTUM BREAK:

Mechanical and Electrical Inertia.

WE mentioned in the last chapter the use of the property of momentum in a pivoted lever as a means of securing the rapid break of an electric contact. Let us consider this a little further, with the aid, if necessary, of fig. 52 in Chapter XII, or fig. 83 in the last chapter, or fig. 84 on next page.

The attraction between the poles of an electro-magnet and its armature increases as the space between them diminishes, according to the law of inverse squares. Consequently, if, when the electric circuit is closed as a result of the gravity lever coming into contact with the armature, the electro-magnetism is sufficient to attract the armature at all, the attraction increases rapidly as the armature approaches the magnet.

When it is half-way, the attraction is not merely twice as much as it was, but four times as much, since it increases according to the square of the diminishing distance.

The armature and the gravity arm have considerable mass and their moment of inertia is also considerable, particularly of the latter, since its mass is disposed horizontally at some distance from its centre.

The job of the electro-magnet being to overcome this inertia and to get both parts moving, it is easy to see what an important part the law of inverse squares plays in increasing the acceleration of the two moving members of the switch, this acceleration reaching its maximum when the armature arrives at the poles of the magnet. There the armature is suddenly arrested whilst the gravity lever is free to fly on.

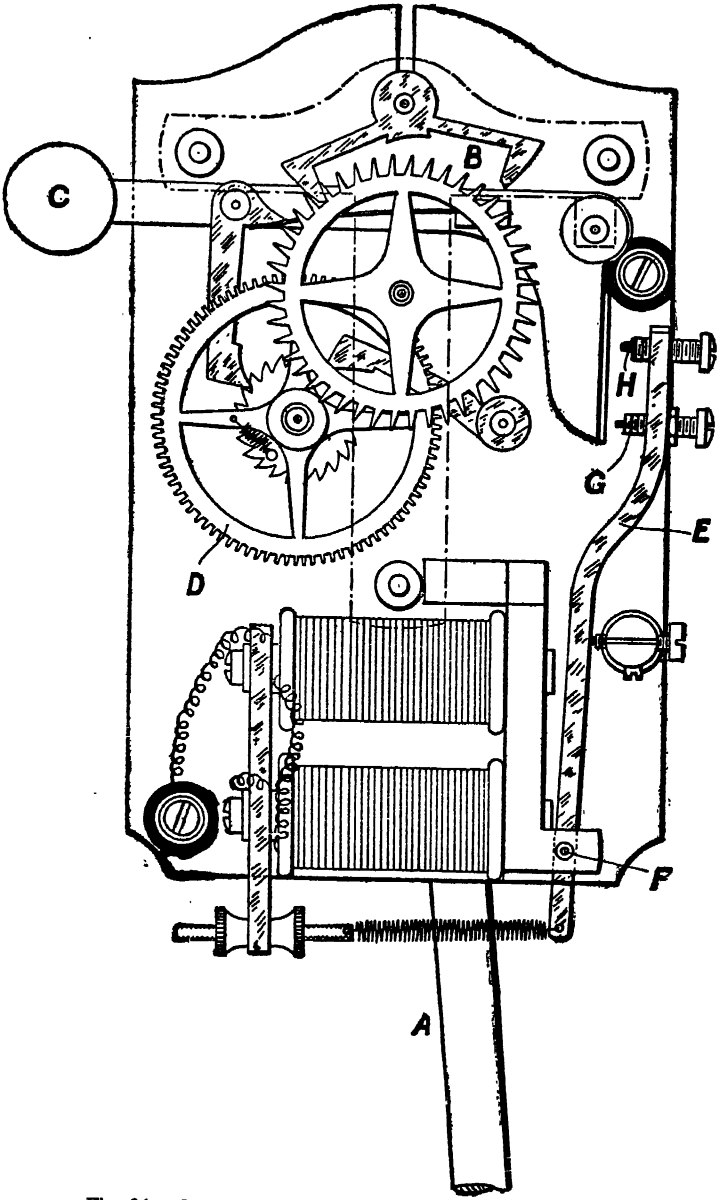


Fig. 84. Synchronome Switch with insulated Push-piece.

At first there was some hesitation in relying upon this momentum to break the electric circuit. In my Paper before the Institution of Electrical Engineers in 1899, I showed how the momentum of the armature could be used to assist the break as well as the momentum of the gravity lever, by the addition of an insulated screw H above the contact screw, as shown in fig. 84, in which it will be seen that the rolling action of two intersecting radials is made use of. Mass was also added to the armature below its centre, pendulum fashion, by which means the duration of the contact could be artificially increased.

Messrs. Gent & Co., of Leicester, substituted a link action for the momentum break in their Patent No. 24620, of 1904, from which fig. 85 is taken. The gravity lever N is at the bottom of the movement with adjustable weight N^1, and the magnet above. The impulse bracket R is on the right hand side of the crutch A, and the impulse pin P is on the gravity lever just above it. The lever Y, pendant from the armature does not itself make contact, but ends in a pivoted trip lever W which pushes forward lever T carrying contact surface S^1 far enough to reset the lever N on its catch O by means of hook M when the rocking of the trip lever W against stop L allows the lever T to fall back. The count wheel and its propulsion is not shown, but at the completion of each revolution, it causes a lever to ride at a lower level and disengage the hook M from the catch O.

But neither of these devices to ensure a rapid break have been adopted since there is no need for them.

It is always better to make use of the forces of nature as a substitute for a more or less complex piece of mechanism. The momentum break is absolutely reliable between wide limits of current variation provided the conditions are properly understood. The motion of the gravity arm must clearly be divided into two parts, its travel in company with the armature, during which it acquires the necessary velocity, and its subsequent

free travel until safely lodged on its catch, and the proportion of each appropriately adjusted.

The momentum break of the switch is due to inertia, and one cannot discuss it apart from *self-induction,* which

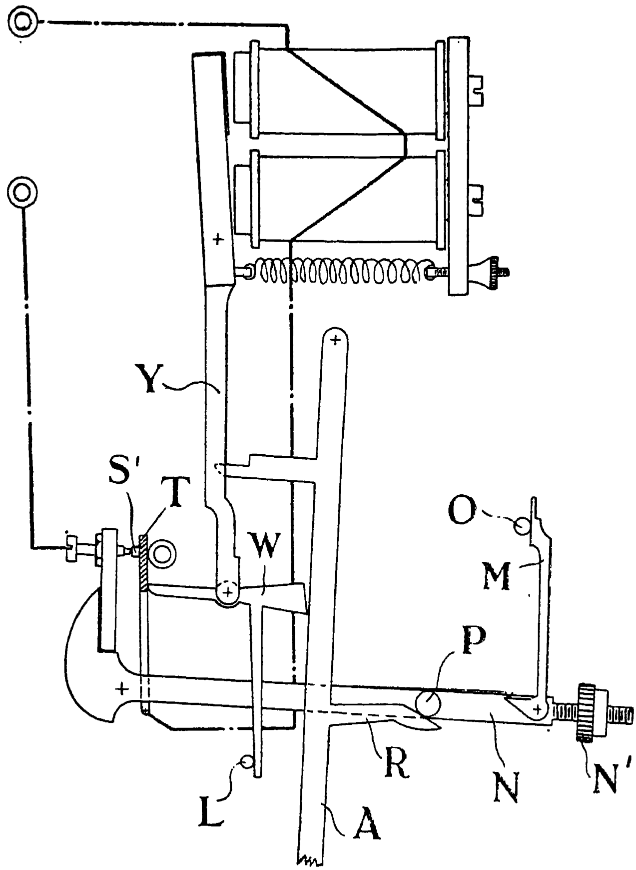


Fig. 85. Gent's link action Contact.

is only inertia in another form, the one being mechanical and the other electrical. Inertia resists motion: in fig. 84 it will be observed that the mechanical resistance and the overcoming of it increases the pressure on the

surfaces of the contact. Self-induction resists the flow of electricity; that resistance and the overcoming of it also benefits the switch by prolonging its action. The soft iron core in a coil of wire constituting the electro-magnet of every clock in the series circuit delays the rise in value of the current, and that delay is imposed upon the action of the switch. Consequently every dial exercises its influence upon the switch in proportion to its requirements, thus if a turret clock with magnet

Fig. 86. Oscillograph of the Synchronome Impulse.

of large self-induction is included in the circuit, the duration of the contact will be considerably increased.

Fig. 86 reproduces a photograph of the electrical impulse which passes through the switch and the series circuit of dials every half-minute, and illustrates the part played by self-induction in dictating the duration of the contact. This photograph is selected from one of a series, taken for me by the late Mr. William Duddell, F.R.S., soon after he invented the "Oscillograph," without which no such revelation of exact truth would be possible. The current deflects a very small and light mirror from which a ray of light is reflected on to a photographic plate moving rapidly in front of it. The plates in this case were supported on a catch at the top of a light-tight slide and fell into a red cloth bag at the bottom. They were partially counter-balanced so that their mean speed was 100 cm. per second. The catch was withdrawn by an electro-magnet controlled by a contact on the pendulum set to operate about a second before the observation, the exact time being readily adjustable to allow for such variations as differ-

ences of weight of the photographic plates. The base line in each curve is, of course, the photograph of the spot before and after deflection. Each vertical division represents one hundredth part of a second and each horizontal division one twentieth of an ampere.

The circuit comprised the master clock illustrated in fig. 88 in the next chapter, and fourteen electrical impulse dials of various sizes, having a total resistance of 60 ohms, and an E.M.F. of 20 volts was applied. It will be seen that when the circuit is closed by the gravity arm sailing into contact at the speed of the moving pendulum, there is no bouncing or chattering, but a perfectly clean make. And note also the precipitous break, showing how instantaneously and cleanly the current is cut off at the end of the impulse.

The best speed for the make was determined by experiment, and it is easily adjustable by (*a*) moving the switch vertically up and down the pendulum rod, (*b*) varying the arc of the pendulum, or (*c*) varying the point in the excursion of the pendulum from left to right at which contact was made.

But the most important lesson which the Oscillograph teaches us is that, although we are accustomed to regard electricity as being instantaneous, it is far from being so. Owing to the self-induction of the electro-magnets in the circuit of electrical impulse dials, the electrical impulse takes an appreciable time to grow to that value at which it is capable of doing useful work.

According to Ohm's law, 20 volts ÷ 60 ohms, should give a current rate of 0·33 amp. at once, but you don't get it, and you may watch it grow throughout the first, second, third, and fourth one-hundredths of a second and consider the feelings of each electro-magnet in the dial movements meanwhile. When the current has reached a value of little more than 0·25 amp., the attractive force is sufficient to draw the armatures of the step-by-step dial movements against their springs. The fact that they have done so is recorded by the little

depression in the curve which is seen between the fourth and fifth hundredth of a second caused by the back E.M.F. or the current induced in a reverse direction by the approach of the armatures to their poles.

Thus the dials themselves have demanded, and received from the switch the current they required, and observe that this was not all the current that was available, but just what was needed. The switch would still give them what they wanted even if the voltage dropped by $33\frac{1}{3}$ per cent. or the resistance of the battery were to increase by $33\frac{1}{3}$ per cent. The master clock could not possibly work at all without giving them a full meal, thanks to the momentum break, with the consideration of which we began this chapter. The explanation is simple: merely that the inertia, the self-induction, and the winding of the Synchronome switch are so proportioned that a higher current rate is required to operate it than is required to operate the dials.

In the Oscillograph we have selected for reproduction, the dials operate at 0·25 amp. in 0·045 sec., and the switch breaks at 0·27 amp. in 0·06 sec., the difference between that and 0·33 amp. being the margin in which the compensatory action of the switch may distinguish itself. And it may be as much more as you like to make it. There is no limit to the margin of battery you may provide.

The area enclosed between the curve and the base line represents the quantity of electricity consumed per impulse, which in this case is 0·012 coulombs, and since the impulses are repeated every half-minute, this equals about $3\frac{1}{2}$ amp. hours per annum. As each dial requires about $1\frac{1}{2}$ volts across its terminals, the annual consumption of energy per dial is about $5\frac{1}{4}$ watt hours.

A Board of Trade unit contains 1,000 watt hours, which in pre-war days cost a half-penny. Not a large sum to pay for uniform and accurate time in two-hundred rooms for twelve months! Economy of current, however, ceases to be of any practical import-

ance in a system in which the consumption is negligible in any event. It is the other benefits that count, and it surprises me that the rest of the world's electric clocks should rely for their contacts upon the touching together of two pieces of metal by extraneous means, purely arbitrary in duration and unendowed with those cardinal virtues such as compensatory action and battery warning, described in Patent No. 6066, of 1905.

CHAPTER XX

BATTERY WARNING: CONTROL OF DURATION OF CONTACT BY SELF-INDUCTION

THE vital principle of the transmission of energy through the surfaces of the contact, which we discussed in Chapter XVIII, led us on in the following chapter to the momentum break and the automatic control of the duration of the contact by the self-induction of the electrical impulse dials.

This compensatory action is so inseparably linked with battery warning that we will now devote a chapter to its consideration.

Any source of electric supply may be used for operating electric clocks, excepting only alternating current, the exception to that exception being the American Telechron clock, which operates on alternating current only, and takes its time from the frequency of the alternations themselves. Though D.C. electric light supply is suitable and often available, it is safe to assume that ninety-nine out of every hundred installations are battery-driven. Both primary and storage cells are available for the purpose, and whereas the life of the former is limited, the latter give practically constant results at the cost of a little regular care in management. They are, therefore, the most satisfactory source of energy for large and responsible time-circuits.

In the case of primary cells of the "dry" type, the limit is usually their ability to resist such natural ageing processes as drying up, which causes a rise of internal resistance and a fall of voltage, whilst the efficient output of wet cells of this type is simply a question of regular and systematic attention. Wet Leclanché cells,

when left alone, are subject to greater fluctuations of internal resistance than their "dry" brothers, and as they rarely receive the attention they require, they are

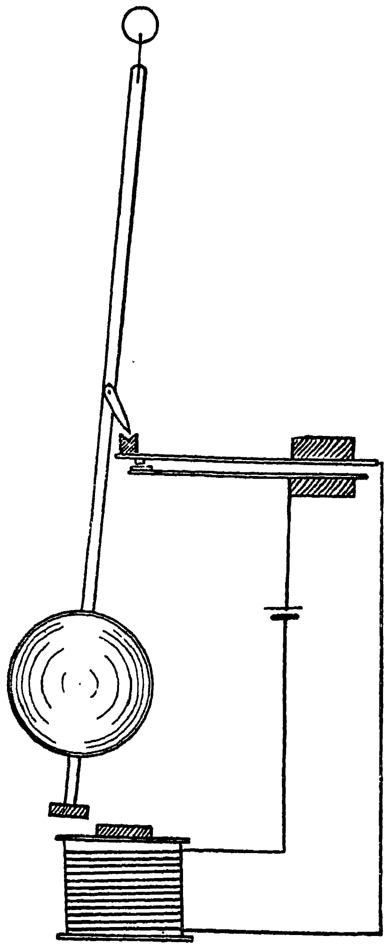


Fig. 87. Hipp's Butterfly Escapement. Battery Warning. The weaker the current, the more often will the contact operate.

not to be recommended, unless automatic warning of impending failure is provided.

We saw in Chapter IX (and fig. 87 will remind us of it) how Hipp's Butterfly escapement provided a most effective battery warning, since the weaker the battery the more often the pendulum helped itself to energy. It is so fascinating to watch the trailer passing over the notched block with diminishing arc until caught that no one could fail to note its more frequent occurrence.

Clearly its merit as an invention was all the greater because it was not deliberately invented, but just "happened." It was an inherent virtue of the Hipp method.

Many attempts have since been made to achieve battery warning with other forms of electric clocks. In the case of electrical self-wound clocks with storage of power in spring or weight, methods have been devised whereby in the event of failure of the remontoire action, an additional contact is made to bring a reserve battery into use, or to cut out an idle resistance. But no devices of these kinds, however ingenious, have justified themselves, and we must come to the conclusion that watch-dogs in the nature of reserve batteries or extra contacts are futile since it is more than likely that they will be found to be asleep when called upon after years of idleness.

What is wanted is a warning which takes the form of a difference in action or behaviour in the fundamental apparatus rather than the application of some clever automatic device super-imposed upon the original invention, and tuned up and ready for instant action though probably not called upon for some years.

Now the compensatory action of the Synchronome switch, which we were discussing in the last chapter, provides this as inherently as in the case of Hipp, but without varying the periodicity of the contact.

The idea was first expressed in Patent No. 6066, of 1905, in the following words:—

"In the event of the electrical energy developed

being insufficient to raise the gravity arm, the return of the pendulum will assist the magnet and the increased duration of contact will automatically indicate the impending failure of current."

To illustrate this effectively, I reproduce in fig. 88 a diagram of a later date.

We have seen that the consumption of current is negligible, but if a battery is used, a time will come

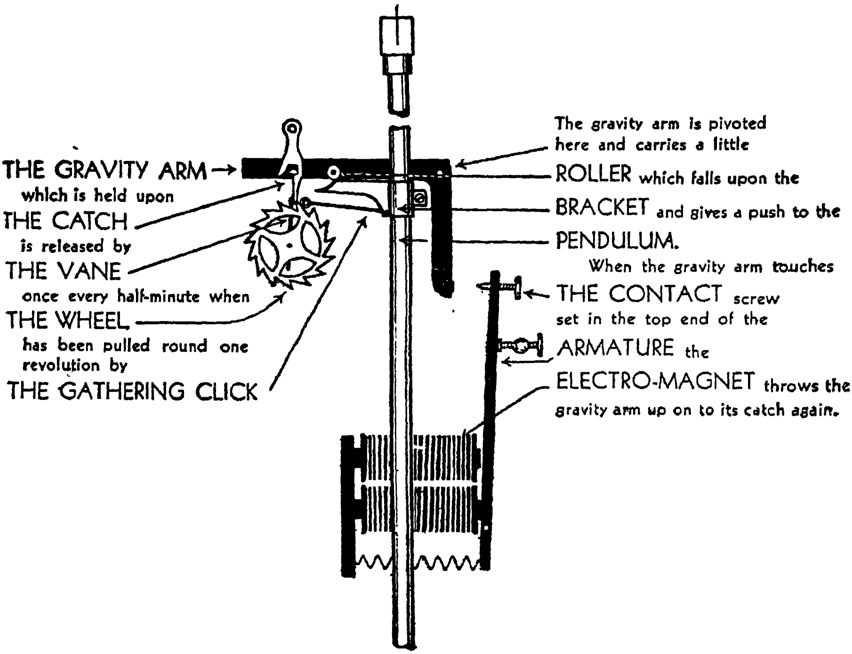


Fig. 88. Synchronome Battery Warning. The pendulum assists the magnet.

when the armature will refuse to move. It will remain in contact whilst the voltage has ample time to break down the self-induction of the electro-magnets and the current will rise to the maximum value which the battery is capable of developing, but the ampere-turns or the attractive force of the electro-magnet is still just not

sufficient to start the armature in motion towards the poles whilst the gravity lever is sitting heavily upon it.

In the meantime, the pendulum having completed its swing to the right, returns, and the impulse bracket finds the little roller on the gravity arm in the way. Naturally enough, when the inevitable collision occurs, the armature being momentarily relieved of the weight of the gravity lever, the magnet will be quite able to complete its job.

What precisely has happened? Normally the gravity lever is thrown up by the armature of the electro-magnet in about six one-hundredths or, shall we say, the sixteenth part of a second. But on this occasion, contact is made shortly after the pendulum is passing its zero position from left to right and is not broken again until the pendulum's return to the same spot. Consequently the duration is suddenly increased to nearly one whole second. This is a most efficient warning, not only by the conspicuous difference in the action of the switch, but also in every one of the electrical impulse dials if they are of the step-by-step kind, since there is always a certain amount of back-lash when the hand is drawn back, and its sitting there for a second and then advancing becomes a prominent indicator of the presence of abnormal conditions.

Thus without the employment of any special apparatus, every clock dial in the building gives warning of impending failure of battery in ample time to enable an addition to be made before any irregularity can be caused.

Without doubt this automatic "reading of the Riot Act" is a most valuable feature whatever type of battery is used and in any electric clock, whether an independent one or a unit in a system of electrical impulse dials.

If this warning is neglected, and if as a result of that neglect the magnet is ultimately unable to replace the gravity arm, even with the assistance of the pendu-

lum, then the pendulum, coming to rest at zero, will hold the switch open, thus preventing the battery from committing suicide by remaining in closed circuit.

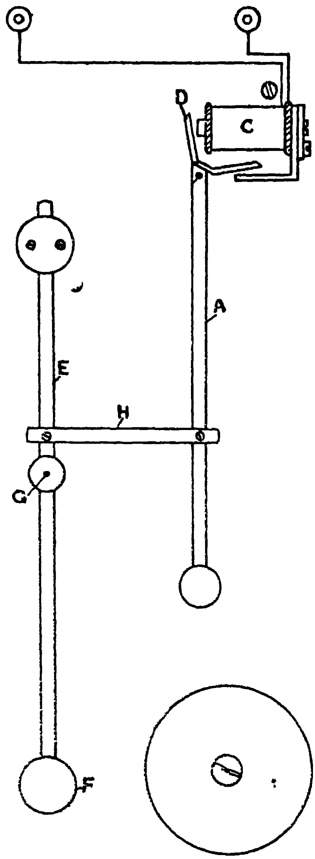


Fig. 89. Gent's Battery Warning Bell.

Messrs. Gent, of Leicester, were quick to appreciate the principle involved, and by means of a clever combination of multiple levers connecting the armature with a bell hammer they produced a battery warning bell, silent under the normal contact of short duration

and ample voltage, but becoming more and more active as the current diminished and the duration of the contact increased.

Fig. 89 is from their Patent, taken out by Messrs. Parsons and Ball in September, 1905, No. 17826. Magnet C is in the series circuit of dials. Its armature

Fig. 90. Synchronome battery warning lamp.

D cannot respond to short duration impulses because the armature lever A is linked by H to an inertia bar E, centred at G, whose lower extremity F is a bell hammer. It can be adjusted to achieve the paradoxical result that the weaker the battery the louder the bell will ring.

If a visual instead of an audible signal is desired, a lamp may be included anywhere in the series circuit, as described in my Patent No. 138708, of 1919. The

smallest size made is suitable, preferably with carbon filament, since its negative temperature co-efficient rather assists the phenomenon than diminishes it, as would be the case of a lamp having a metallic filament with positive temperature co-efficient.

The lamp may be placed behind red glass and surrounded by a suitable notice as illustrated in fig. 90. But it is found in practice that the average user considers them to be puerile and appropriate only in a girls' school.

Just as the motor-cyclist knows when his engine is misfiring, so anyone who is interested in his electric time circuit in his house or office or works becomes aware of its sluggish action and understands it.

CHAPTER XXI

GRAVITY ESCAPEMENTS: SEMI-DETACHED

I OWE an apology to my purely horological readers for having devoted the last three chapters to electrical matters, but we were led on irresistibly by a succession of features which were closely linked together—the transmission of energy through the contact surfaces, the momentum break and battery warning.

Having established the importance of these matters and above all the importance of giving the impulse at wide intervals instead of every second, we will revert to the horological side and take up gravity escapements where we left them in Chapter XI.

What precisely do we mean by a gravity escapement?

Obviously it implies a lever or gravity arm bearing directly upon the pendulum with all its weight as it falls. To most of us it means Grimthorpe's four-leg or double three-leg as designed for Big Ben in 1854, and since generally adopted for turret clocks. It is so well known that it hardly needs fig. 91 to illustrate it.

The two three-legs, ABC and *abc*, in different planes, have one set of three lifting pins between them. The pallets also lie in one plane between the wheels, but one stop (S) lies forward to receive the ABC teeth, and the other (S^1) backward to receive the *abc* teeth alternately.

Cummings originated the idea of this escapement in the eighteenth century; Reid has it in his Treatise, published in Edinburgh in 1826, with springs instead of gravity arms; Mudge carried it a stage further, but it was Bloxam, in 1850, who really invented it and Grimthorpe merely improved upon his design.

What are its salient features?

The pendulum picks up the gravity arm at A (fig. 92), raises it to B and returns with it to C, the difference between A and C being the impulse. The replacement

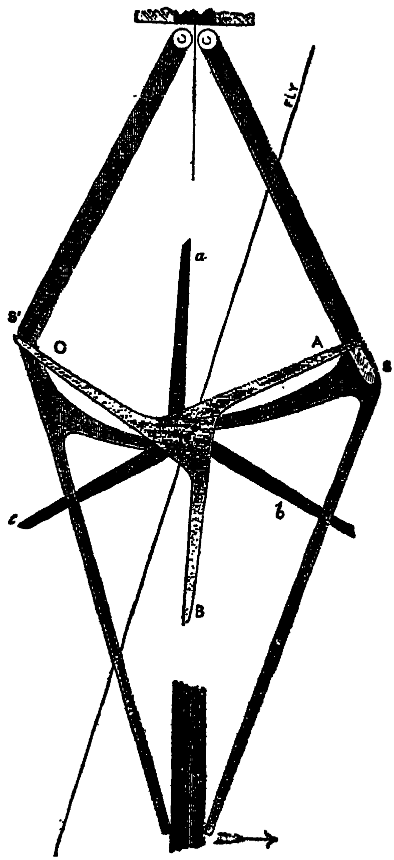


Fig. 91. Grimthorpe's Gravity Escapement.

of the gravity arm is the remontoire principle pushed to its uttermost since the re-winding and replacing of the gravity arm takes place directly and immediately after it has fallen. The storage of power is the minimum and the frequency of its operation is the maximum.

Harrison was the great exponent of the remontoire principle and carried it further than anyone else in the going train of a clock, but not as far as Bloxam, who made a remontoire of the escapement itself.

The great merit of the remontoire principle, is, of course, that variations in friction in the going train are not communicated to the escapement, an invaluable

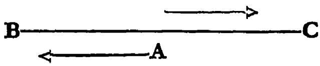


Fig. 92.

feature in turret clocks with hands exposed to the weather.

The lifting of the gravity arms is accomplished by pins near the centre of the 'scape wheel where the power is great, and unlocking is done at the far ends of long radial arms where the friction is least.

The inevitable variation in that friction does not tend to compensate the circular error as in the Graham dead-beat escapement. It gives you a uniform driving force balanced against a variable unlocking force. Nevertheless, the Grimthorpe gravity escapement was a great achievement and is not the least of the inventions which have maintained Britain's supremacy in horology. It has dominated turret clock practice throughout the world since Big Ben was first set going in 1860, and is only now beginning to give ground—slowly, inch by inch—to the direct electrical propulsion of turret clock hands.

In Chapters X and XI we described the electric gravity escapements of Froment, with its variations by Gill and Féry, Prince and Robertson; also that of Steuart, who uses a continuously running motor.

All these are, in effect, the Bloxam-Grimthorpe gravity escapement with this difference—that the pendulum is not called upon to release the remontoire for the replacement of the gravity arms.

In the case of Froment and Prince, springs are used as gravity arms, but the principle is the same, just as the Reid-Winnerl escapement as made by Le Roy for the Paris Observatory and for Edinburgh is Cummings', but for the substitution of springs for gravity arms.

Some have called them free pendulums, but I cannot admit them into that category since no pendulum is free, which is subjected to the interference involved in picking up a gravity arm or spring towards the end of the swing and receiving its impulse by the difference between its lift and fall.

From whatever point of view we look at this escapement, the fact remains that the gravity arms or springs (which have a law of their own) are an interference with the freedom of the pendulum, and this interference is in that part of its path where its effects are most prolonged and most harmful.

It is often stated that if the impulse is uniform, then the interference is uniform and time-keeping would not be affected. It is claimed that the gravity arms are invariable in their weight and in the distance of their fall, and that consequently their effect should be uniform. Let us admit that if the arc was constant the interference would also be constant; but it is a foregone conclusion that the arc will not remain the same—to mention one source of disturbance alone—variations in the barometer will affect it. Can it be suggested for one moment that a pendulum can vary the distance it has to carry the burden of a gravity arm up and down hill at the end of its swing, without varying the time of its vibration?

When it is realised that a gravity arm adds to the mass of a pendulum at a point above the bob, and therefore raises its centre of gravity and shortens its effective length, it will be seen how futile it is to suggest that the proportion of "with and without" in the time of each swing can be varied with impunity.

Thus, we have seen that the gravity escapement can never achieve the highest precision even though

the pendulum is relieved of the duty of discharging the remontoire. Further, that such a pendulum can never be said to be free; actually, the interference is almost continuous, or of the order of nine-tenths of each second; that is to say, nine-tenths of the total time measured.

In the new free pendulum clocks at Greenwich and other observatories, the interference is confined to a period of about one-hundredth part of the time measured and that is the interference due only to imparting the impulse to the pendulum. There is no other interference of any kind whatever, and it will now be my object, having reviewed most of the other methods and systems and shown why they have failed to contribute to the science of accurate time measurement, to trace, step by step, each improvement which has led to the establishing of a new standard of accuracy for observatory clocks.

The principal foundation-stone is the Synchronome switch, or remontoire, which we shall see is destined to play the most important part in every successful variety and type of free pendulum now or to come, but from the horological side of the problem as distinct from the electrical, the principal foundation-stone is the *detached* gravity escapement.

The first electric gravity escapement which I described—that of Shepherd (in Chapter X), had what I should call a *semi-detached* gravity escapement, if I were allowed to coin a new term in clockmaking. The pendulum releases the gravity arm as nearly as possible at the end of its swing. Having delivered its impulse, the gravity arm is thrown up by an electro-magnet, thus leaving the pendulum free for the remainder of one complete vibration.

Geist, of Wurzburg, did the same, but greatly improved the method of delivering the impulse. I illustrate in fig. 93 the armature A, which, you will see, is supported on the catch B until the bracket P on the pendulum releases it. The armature (which is, of course,

simply a gravity lever) then falls with its roller and exerts its main effective pressure on the pendulum when it rolls over the corner of P. I also show his electro-magnet M and contact C; but I do so only as a joke because my readers now know the imbecility of letting a pendulum barge into a spring. In these respects, Geist is as crude and futile as Shepherd, but we respect them both as pioneers.

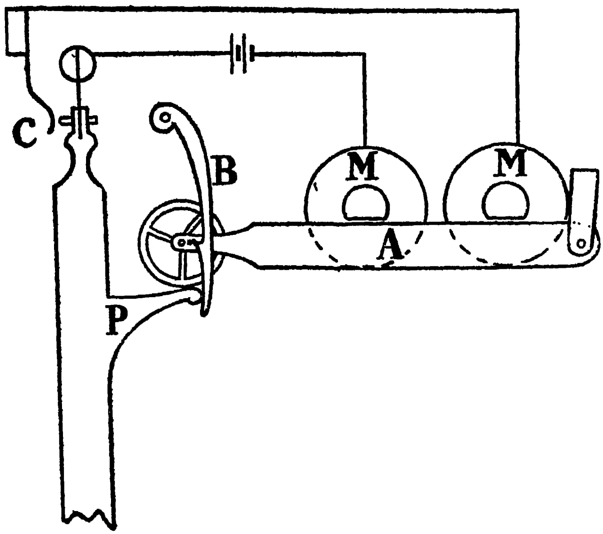


Fig. 93. Geist's Gravity Escapement.

I adopted his semi-detached escapement in 1905, applying it to my patent of that year; so did Messrs. Gent, of Leicester, and in my article in the *British Horological Journal*, of January, 1906, I described and illustrated it (fig. 94) as follows:—

"The top surface of the pallet J, fixed to the pendulum D, forms an arc of a circle whose centre is coincident with the centre of suspension S. The pallet may, therefore, run so close under the little wheel H on the gravity arm A, that the drop is imperceptible,

and will be uniform in spite of variation of arc or point at which the release occurs. The impulses are uniform

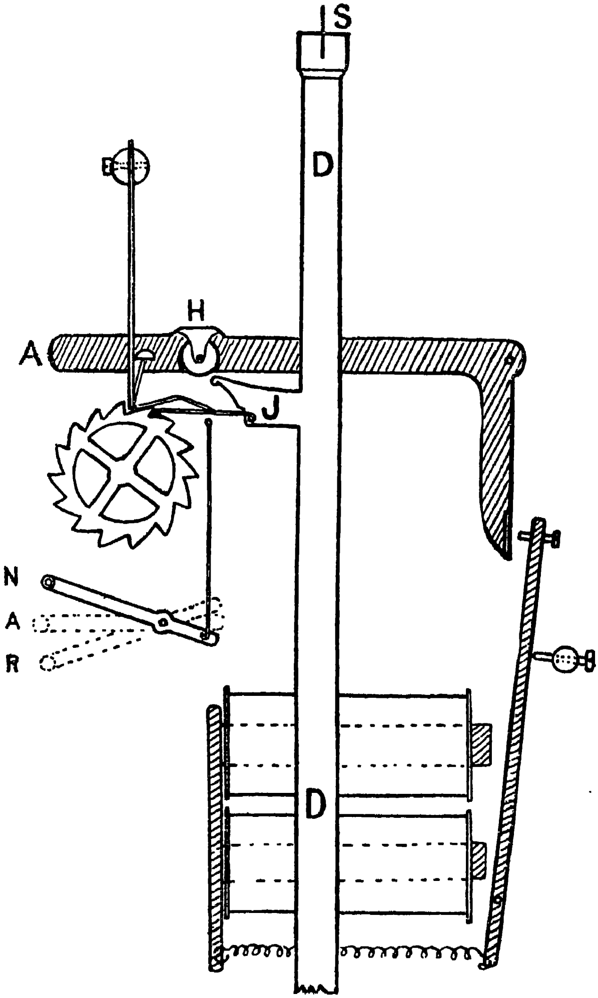


Fig. 94. Semi-detached Escapement patented by Mr. F. Hope-Jones in 1905.

in strength and position, and even possible minute elongation of impulses due to wearing away of the

contact surfaces may be provided for by allowing the impulse wheel *to fall off the pallet just before contact is made*."

I have italicised the last line because some years of progressive improvement had to pass by before its importance became apparent.

All the rest of it has been freely adopted and though I looked upon it merely as a stepping-stone to something better, others have considered it good enough for providing commercial accuracy.

Reverting to my metaphor, the objection to "semi-detached" houses is that we get too much of the neighbours' piano, gramophone, or loudspeaker; similarly, in semi-detached escapements, we have no elbow room, but charge into the releasing catch at the end of the swing and receive a push.

In the next chapter we will see to it that if there is to be any interference with the free swing of the pendulum, it shall take place at or near the middle of its swing, according to the law that is like unto the law of the Medes and Persians, which altereth not. This demands a completely detached gravity escapement, and will require a separate chapter.

CHAPTER XXII

GRAVITY ESCAPEMENTS: DETACHED

IN the last chapter, we saw what the trouble was with gravity escapements. The gravity arms or impulse levers are associated with the pendulum almost continuously. If only we could arrange for a gravity arm to give its impulse and then get out of the way and keep out of the way, then the pendulum might be relied upon to fulfil the great duty for which nature has intended it. And if, further, that impulse could be imparted to the pendulum when it was passing through its zero or central position, then there is no reason why it should not achieve its predestined perfection of time measurement.

Tompion "sensed" this, but he never achieved it. Graham does not appear to have discussed it, and we can hardly blame him for thinking his own dead-beat escapement good enough since it was good enough for precision clocks of the world for about 150 years, from 1740 until 1890, when Riefler came on the scene.

The detached escapement was first realised in the marine chronometer. Not by Harrison; he only accomplished that greatest achievement of all—the proof to mankind that it was possible to produce a marine timepiece capable of determining longitude.

He did not invent the chronometer, though he made the first marine time-keeper. If that invention must be credited to any one man, it must be to him who made the first detached escapement with impulse at zero, and that was Pierre Le Roy in 1746.

With or without knowledge of that invention, with or without the benefit of Mudge's and Berthould's

contributions to the science, it was Arnold and Earnshaw who equipped our Merchantile Marine with chronometers and taught Britannia to rule the waves.

The very soul of its success was the detached escapement giving its impulse across the line of the centres, illustrated in fig. 95, in which AB is the 'scape

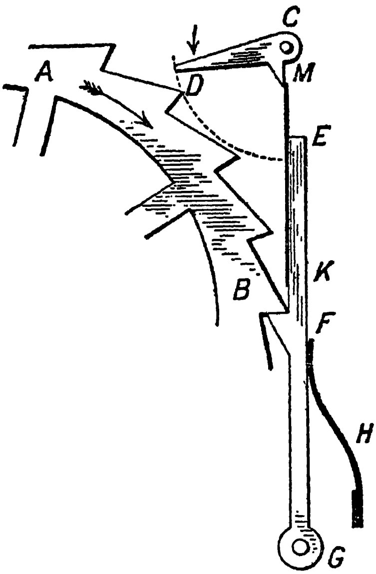


Fig. 95. Chronometer Detent Escapement.

wheel and CD a fitting on the balance wheel. It will be seen that the 'scape wheel is normally locked by the step F on the lever GE, but is released by M when the balance wheel revolves in a counter-clockwise direction by a light one-way non-return gold spring. The 'scape wheel AB then jumps forward rapidly and the tooth D imparts an impulse to C just when it is passing through the line connecting the centre of the balance wheel C with the centre of the 'scape wheel.

The merit of the chronometer detent escapement is so obvious that one wonders why a greater and more

sustained effort was not made to apply it to clocks before.

One attempt appeared anonymously in Rees' Encyclopaedia, from which I take my fig. 96. The pallet A fixed on the pendulum at B carries a pivoted catch C which rides over the lever D on its way to the right

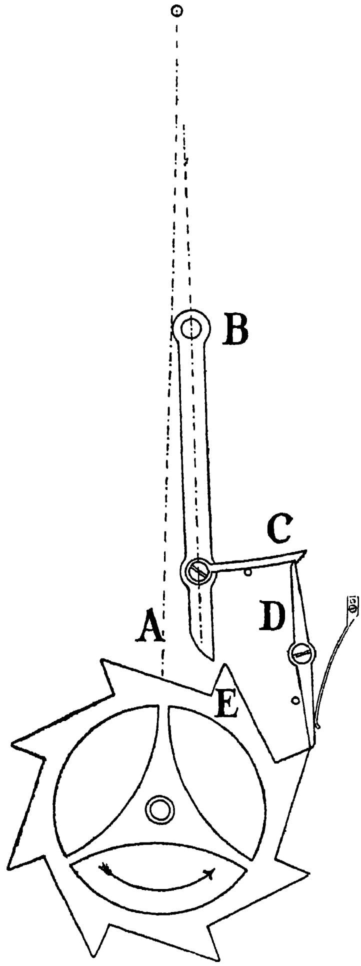


Fig. 96. The Chronometer Escapement applied to a Pendulum.

and trips it on its swing to the left, thereby releasing the 'scape wheel just before the pendulum reaches zero, when A is in a position to receive an impulse from the tooth E

There is, of course, an intrinsic difficulty in this mere adaptation of the chronometer escapement to a pendulum. In the former, the comparatively small radius of the balance wheel enables it to get out of the way of the 'scape wheel rapidly while the pendulum on the other hand can only have a very light and delicately adjusted engagement with it which is not easily achieved at its lower end.

Lord Grimthorpe, in his "Clocks, Watches and Bells," says he made one which was quite successful, but he passes on to the gravity escapement of his adoption with which he is apparently quite content.

Nothing further was done along these lines if we except Rudd, who accomplished it and a great deal more in 1898, but his achievement passed unnoticed at the time and its story must be deferred until we come to the period in which it was discovered and in which it exercised its influence on the science.

It is Sir Henry Cunynghame whom we have to thank for championing its application to pendulums and demonstrating its practicability.

It is curious to note how many horological inventions of distinction have emanated, not from clockmakers, but from lawyers. He was a barrister and first legal Secretary at the Home Office. Following Bloxam and Grimthorpe, both lawyers, one sees the affinity between the legal and the scientific mind, of which I have had exceptional experience, having been privileged to share the enthusiasm of judges, barristers, and solicitors, in the pursuit of that elusive will-o'-the-wisp, absolute accuracy of time measurement. Among these I would recall the late Lord Alverstone, best loved and known to us Victorians as Sir Richard Webster, Q.C., W. R. Bousfield, K.C., Russell Clark, K.C., John

Hunter Gray, the brilliant Patent Counsel, and Mr. A. T. Hare, a Treasury Barrister.

Thus horology offers a striking example of the value of the amateur in invention. The professional is very apt to get into a rut; he needs to be shaken up by the amateur who approaches the subject from a fresh point of view, uninfluenced by the traditions of the craft or the dogmas of the text-books and capable of an immense enthusiasm.

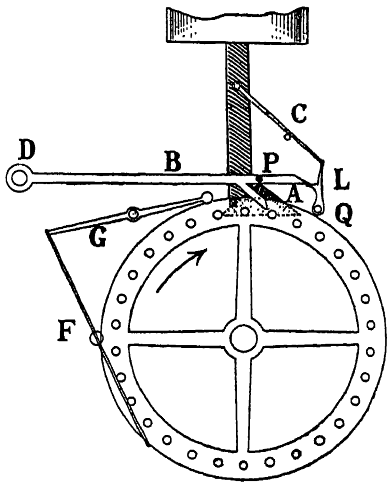


Fig. 97. Sir Henry Cunynghame's Detached Gravity Escapement.

Such a one was Sir Henry Hardinge Cunynghame, K.C.B., a man who never touched *any* subject without illuminating it. In 1904 he made a mechanical clock with detached gravity escapement. In that year he gave the series of lectures held every Christmas at the Royal Institution of Great Britain, always announced as "adapted to a juvenile auditory," since it would be beneath the dignity of that august body to refer to them as for children! He chose as his subject "Time and Clocks" and exhibited a model of his clock which I illustrate in fig. 97.

A triangular piece of steel A is fixed at the extreme lower end of the pendulum under the bob, the left hand inclined edge of which forms the impulse surface, and is fixed centrally. The gravity lever B centred at D and carrying an impulse pin P near its free end, is supported on the trigger L centred at Q. This support

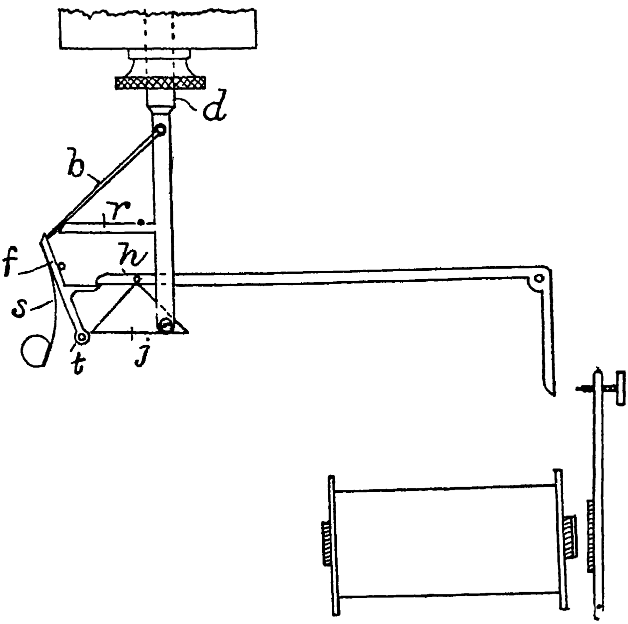


Fig. 98. The Cunynghame-Hope-Jones Patent No. 1945, 1907.

is removed by means of a flipper or chronometer spring C carried on the pendulum just before the pendulum arrives at zero, and when the apex of the triangle is immediately below the impulse pin during its excursion to the right.

The large wheel E, with pins on its periphery and a fan F gearing it, constitutes the quick-moving end of a weight-driven train, which serves to replace the gravity arm. When the latter falls upon the lever G

it releases the fan for half a revolution, and a pin on wheel E re-sets the gravity lever B on catch L.

It was inevitable that Sir Henry Cunynghame and I should fall together over this, since his gravity lever B in fig. 97 only required the addition of a right-angled arm to engage a vertical armature in order to convert it into a Synchronome switch. This combination was achieved when he gave a lecture at the British Horological Institute in December, 1906. It was patented in 1907, Patent No. 1,945, from which fig. 98 is taken. In this form it was used for timing motor cars for the British Automobile Racing Club's new track at Weybridge, and it was exhibited at the Royal Society of Arts in his Cantor Lectures of January and February, 1908.

CHAPTER XXIII

THE SYNCHRONOME DETACHED GRAVITY ESCAPEMENT

THERE have been many gravity escapements which were not detached and many detached escapements which were not gravity. Sir Henry Cunynghame's was *both*, and one which delivered the impulse at the middle of the vibrations of the pendulum. And the gravity arm of this escapement requires no clock movement or other mechanism to re-set it. It is promptly and reliably re-set after every fall because it itself forms part of the Synchronome remontoire, of whose other merits we have already learned something.

It might well be asked, what more can be expected of an escapement? The impulse is uniform since it consists of the same weight falling the same distance every time. In this respect it is better than the chronometer escapement whose impulse is delivered by a 'scape wheel at the quick-moving end of a train of wheel-work and is therefore subject to whatever variations in friction may develop in that train; and in a chronometer escapement such variations affect the releasing friction as well.

In this escapement there is no train of wheel-work with its inevitable variations of friction, and if there were, variations could not be felt by the pendulum in any event, since the gravity arm is detached. Consequently the releasing friction is also constant.

With respect to its zero impulse, it is on a par with the chronometer, since the pendulum is absolutely free after it has received its impulse and likewise throughout the extremities of its vibrations—that part of its swing

when it is doing most of the time measurement, and when the slightest touch will disturb it.

This reads like a catalogue of all the virtues, yet it was not a practical success in this form; it was not introduced nor put "on the market."

Its history reminds one of the truth which cheered so many of our special constables and volunteers on duty during the war, that "they also serve who only stand and wait." These principles were all vital and necessary. Without them, the recent achievements in precision time measurement could never have been realised; they were tried out and marshalled, but they had to wait for 15 years for their proper expression and use, in the highest grade of service.

Some of the practical difficulties can easily be realised from the illustration, fig. 98, in the last chapter. The triangular form of the impulse block at the bottom of the pendulum is necessary to prevent the apparatus smashing itself in the event of an electrical disconnection failing to re-set the gravity lever, whilst the placing of the movement under the bob involves tying it to the pendulum suspension by means of metal rods of the same co-efficient of expansion as the rod.

The mildest expression one can use of this disposition of the parts is that it is a nuisance. The constructional difficulties involved can be overcome in laboratory instruments, but are highly undesirable in a standard pattern for reproduction. Yet it had been a general practice among horological inventors to try out a new escapement by beginning underneath the bob, born probably of an instinct to apply the impulse to a moving mass as near as possible to its centre of gravity. Sir Henry Cunynghame still favours it. The first of the Synchronome Free Pendulums erected by Mr. Shortt with his own hands in December, 1921, at Edinburgh Observatory, was designed in this manner, but in subsequent patterns the movement was raised to its customary position of seven inches below the suspension

But the real trouble lay in the releasing of the gravity lever at each vibration. Too much energy was taken out of the pendulum in that operation, and it proved anew what had already been demonstrated to my complete

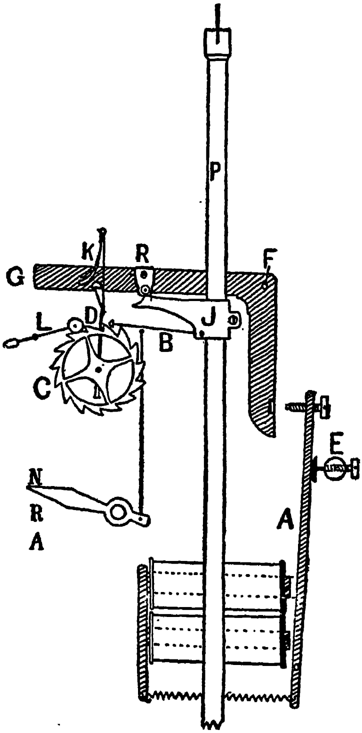


Fig. 99. Synchronome Electric Time Transmitter, 1907.

satisfaction some years earlier that the solution lay in occasional impulses instead of impulses every second or two seconds, even at the cost of having to ask the pendulum to operate a count-wheel.

In that form it was forthwith established as the standard half-minute escapement of the Synchronome system, as illustrated in fig. 99, the original feature being

that the gathering hook B rides over the tips of the teeth of the wheel C on its excursion to the left, and gathers one tooth when passing through the zero position on its excursion to the right. The release of the catch K is accomplished by the vane D once every revolution just before the pendulum arrives at zero. The gravity lever G pivoted at F then falls and the roller R runs down the impulse surface of the bracket-pallet J on the pendulum P. L is merely a back-stop.

Those of my readers who are interested in the origin of the modern system of half-minute electrical impulse dials will remember my essay in Chapter XVII on the hide-bound custom of the almost continuous impulsing and locking of escapements, and how its drastic reform into half-minute impulses bears upon the transmission of energy through the surfaces of the contact, which matter was dealt with in the next chapter.

In fig. 100 it will be seen that the time counting on an idle wheel which the pendulum is called upon to

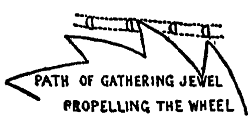


Fig. 100. Frictionless Propulsion.

perform may be a very light job. A small French pallet jewel on a light steel arm is, perhaps, the best form of gathering hook. A light engagement suffices, and the interference may be strictly limited to a few minutes of arc on each side of zero.

With regard to the unlocking friction, superficial criticism has sometimes suggested that since the impulse is fifteen times normal, the unlocking friction and variations thereof are also fifteen times normal, forgetting that the factor which matters is the time during which such disturbances are free to act on the pendulum.

The total period during which a pendulum is subject

to interference should always be compared with time itself, that is to say, the total time measured. A pendulum is only safe from interference when it is absolutely free.

It would be instructive to review all known escapements from that standpoint and to place them in an order of merit based upon the degree of their freedom. Such a list would begin with Harrison's Grasshopper in which the escapement is at work all the time and the pendulum is never free and would end with the Shortt Free Pendulum in which the interference is confined to one part in one hundred of the time measured.

Fig. 99 also serves to illustrate the method adopted for setting forward and backward a circuit of electrical impulse dials. The letters N R A on the lower left hand side of the illustration show three positions which a lever may occupy. It is Normally at N, but when depressed to R the stiff wire rising from its rear end which is bent forward at right-angles at the top, raises the gathering click B out of engagement with the wheel, thus disconnecting the pendulum from the switch with the result that all the dials in its circuit are Retarded. When the lever is further depressed to A the gathering click B is raised into such a position that it releases the catch K every two seconds, thus Advancing all the dials in the ratio of 15 to 1.

This is an opportune moment to refer to the introduction of Daylight Saving and to the service which this invention rendered in the campaign in favour of that reform, opened by Mr. William Willett in 1907.

The watch and clock making profession took it badly, and prophesied dire results and trouble from monkeying with the nation's clocks. Their opposition to Mr. Willett's first proposal of a gradual change effected in four stages of twenty minutes per week was very commendable and was ably stated by Mr. T. D. Wright before a Select Committee of the House, but the profession as such had no grounds for opposing

Daylight Saving in general, or the hour change in particular, and I pointed out (*The Spectator*, 29th September, 1907) how the introduction of electric time service would prepare the way for this reform and facilitate changing the time of vast numbers of clocks in bulk in the spring and in the autumn.

This prophesy has been amply fulfilled, light work being made of the hour change twice a year on fifteen thousand clocks on the Synchronome system in London alone.

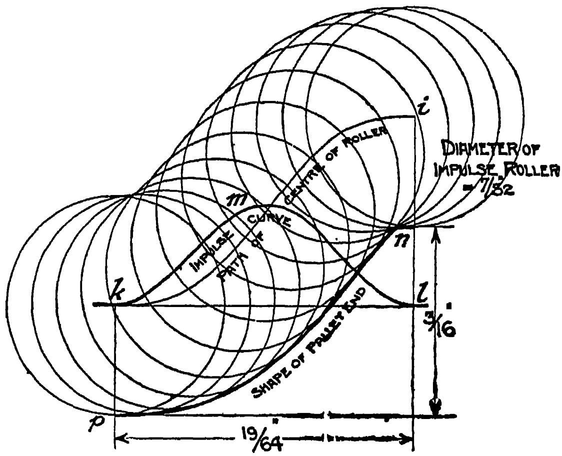


Fig. 101. Mathematical Expression of Synchronome Impulse, given by Mr. W. H. Shortt

I mentioned in Chapter XVIII that it was desirable, when imparting to the pendulum a concentrated impulse of considerable power every half-minute, that it should begin gently, increase in value until it reached a maximum at zero and then tail off with equal gentleness. When describing the Synchronome system at the Institution of Electrical Engineers in February, 1910, I drew a force curve and showed how the end of the pallet J should be shaped to achieve this. In the discussion which followed that paper, Mr. W. H. Shortt, M.Inst.

C.E., contributed a mathematical solution of its best form, which I give with the assistance of fig. 101.

The normal arc of the pendulum may be taken as such that a point say 13″ below the suspension will travel a distance of $\frac{3}{4}''$ and the impulse is concentrated into say $\frac{1}{4}''$ or one-third of every fifteenth excursion from left to right. The roller on the gravity arm which delivers the impulse is 7/32″ diameter and one has to consider what path the centre of this roller shall take to achieve a horizontal component thrust, varying in force in accordance with this requirement.

The curve *i k* (fig. 101) shows the path that the centre of the roller should take in order to achieve the ideal mechanical force curve *l m k*. The vertical elevation of any point on this latter curve above its base line is, of course, the measure of the horizontal driving force at that point of the pendulum's path. The curve *i k* is given by a portion of the curve $y = x - \sin x$, from $x = o$ to $x = 2\pi$, and since the horizontal driving force is directly proportional to $\frac{dy}{dx}$ the impulse curve is represented by the portion of the curve $y = 1 - \cos x$, from $x = o$ to $x = 2\pi$ which gives *l m k* in which the horizontal driving force is zero at the beginning and end of the impulse.

It was in connection with this paper at the Institution of Electrical Engineers in 1910 that I first met Mr. Shortt. Though a small matter in itself, it was the beginning of an association which was destined to achieve important results, and it has endured ever since, much to the advantage of the author.

Mr. Shortt took up horology in that year and accepted as its then greatest achievement and highest exposition of the art the Synchronome-Cunynghame escapement below the bob, with impulse and contact at every other second. His experimental work was based upon it, and his scientific research was devoted to ascertaining its faults and curing them.

CHAPTER XXIV

THE DEATH AND BURIAL OF TWO FALLACIES

I HAVE spoken of the predilection of inventors to try out new escapements underneath the pendulum bob, and of the hide-bound custom of giving impulse every second. These bad habits died hard and there was some excuse for them, particularly for the latter, since the gravity arm was replaced by the Synchronome remontoire, providing thereby a reliable switching action every second so much desired in observatories, physical laboratories and wherever accuracy of time measurement was demanded.

These two features dominated the first five years' experimental work of Mr. W. H. Shortt, which he began in 1910. The story of the development of the invention during this period was unfolded by him in a lecture before the British Horological Institute, appearing in their journal in the issues of May and June, 1928. Its educational value was undeniable, particularly his investigations of frictional coefficients, yet one cannot help regretting that it should have taken so long to prove that it is undesirable to unlock an escapement by direct collision at high speed and that impulses every second must give way to widely spaced ones; a fact already demonstrated by the successful commercial development of my half-minute system in the previous five years, the period 1905-1910.

He began in 1911 by following up an idea contributed to the discussion of my Institution of Electrical Engineers' Paper, substituting a wheel for the triangle at the bottom of the pendulum, and loading the gravity arm with an inertia bar E as shown on the left of fig. 102.

He substituted a spring blade for the top end of the armature N and was thus able to let the pin B^1 on the gravity lever L and the impulse wheel A^1 on the pendulum part company when the former fell on to the armature to make contact and get itself re-set, not simply

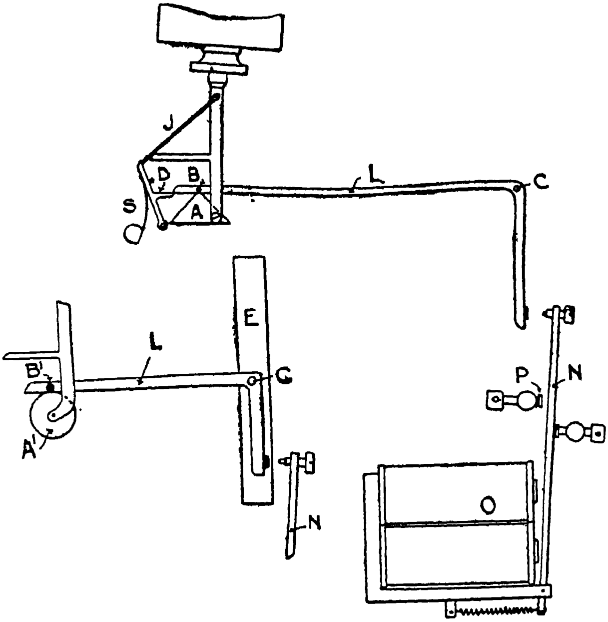


Fig. 102. Mr. Shortt's development of the Hope-Jones—Cunynghame Synchronome switch, showing the wheel at the bottom of the pendulum instead of the triangle.

as in my 1905 Patent (mentioned in Chapter XXI, fig. 94), but in this case, owing to the large moment of inertia of the gravity arm and its slow acceleration due to gravity relatively to the speed of the pendulum at the middle of its path, the point at which they parted varied with the arc, thus providing automatic compensation since the impulse diminishes as the arc increases and vice-versa. Fig. 103, reproduced from the *British Horological Journal* of January, 1912, will

sufficiently explain the compensatory action of this "Inertia" escapement and fig. 104 will show how it was applied. The V-shaped block K at the lower extremity of the pendulum engages the trigger J at zero and releases the gravity arm B every second. E is the inertia bar and M the spring extension of the armature N. The catch D is disengaged by the rocker H.

A dozen of these instruments were made and tried out on responsible jobs, but they never excelled the

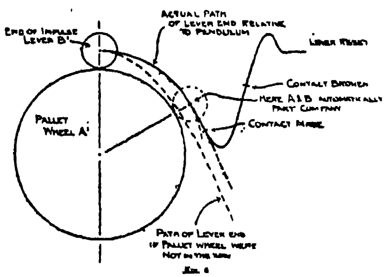


Fig. 103. Mr. W. H. Shortt's "Inertia" escapement and its compensating action.

performance of the ordinary standard Synchronome Master Clock with impulse and contact every half-minute.

Then followed a long course of patient experimental work in which Mr. Shortt took the lead, assisted by the Synchronome Company's workshops, only interrupted by his leaving for the front as a Capt., R.E., in 1916.

There was reason to fear that the release was taking nearly as much energy as the pendulum, so the size and weight of the gravity lever was reduced to its extreme limits in order to reduce the releasing friction and to avoid excessive arc of the pendulum. These limits were soon found to be (1) unsafe locking, (2) large and variable pivot friction relatively to the small forces dealt with and (3) insufficient mass to ensure a good switch.

It was this latter, and my inexorable demand for a substantial Synchronome lever, that led Mr. Shortt to

disassociate the two functions of impulsing and switching and to provide a separate lever for each, a light one to give impulse and a heavy one to make contact, the

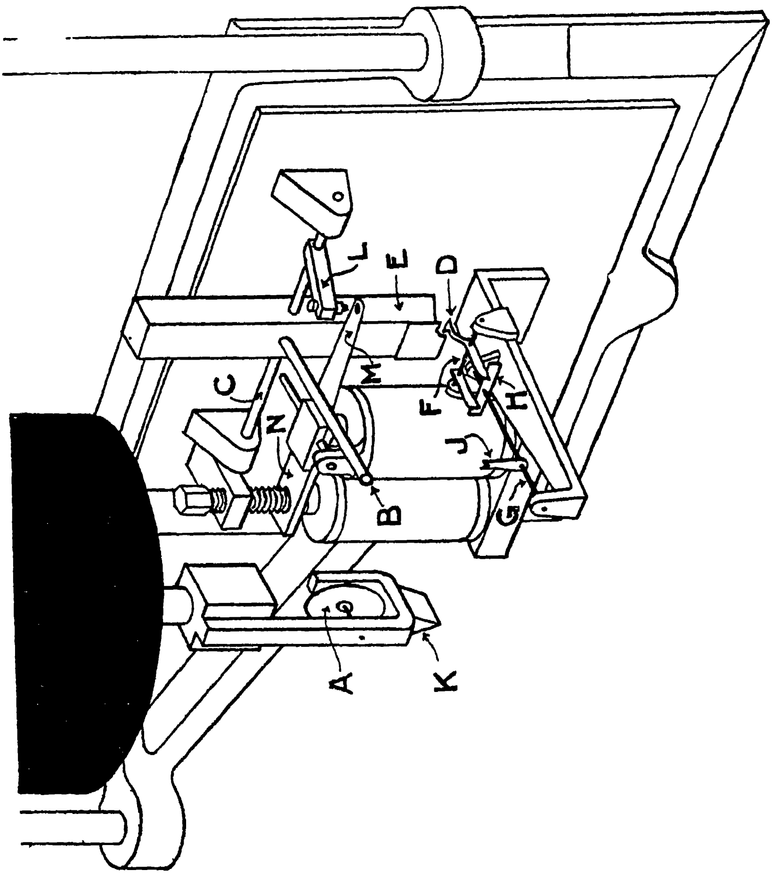


Fig. 104. The "Inertia" Escapement.

latter being arranged to re-set the former mechanically by taking hold of it gently, lifting it slowly, and placing it gently upon its catch.

In fig. 105 the light steel gravity lever L is shown in the foreground pivoted at C and ending at the left

in a jewel B^1 which falls upon the wheel A^1 on the pendulum or its crutch, when the latter has released it from a catch not shown. After it has dropped off the impulse wheel A^1, the gravity lever L, by means of adjustable push-screw D, releases catch K, supporting the Synchronome switch lever G. When G falls, the roller E mounted thereon gently lifts L on to its catch by its cam action. This was tried out both below the bob and near

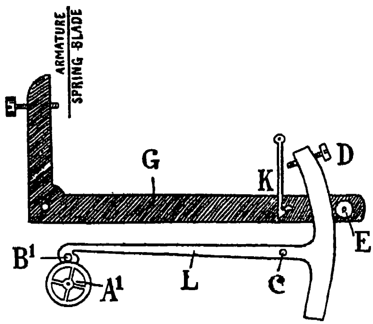


Fig. 105. The two levers from Mr. W. H. Shortt's Patent No. 9527, 1915.

the top of the pendulum. In the latter form it was put on test at Edinburgh Observatory and Professor Sampson, F.R.S., made a mathematical analysis of the escapement in the first of his four papers on Clocks, contributed to the Royal Society of Edinburgh.

The tests proved that although some of the original difficulties had been satisfactorily overcome, certain others had been introduced, and that the energy consumed in effecting the release still amounted to some 10 or 20 per cent. of the total energy supplied to the pendulum, and that the introduction of the crutch was a retrograde step.

An investigation was then made into the comparative rate of fall of the arc of the pendulum, first of all when swinging freely, and secondly when operating the catch, *i.e.*, releasing the impulse lever, but not giving

impulse to the pendulum. By noting the variation of rates of decrease of arc, one could get a fair idea of the amount of energy used up in effecting the release. The result of the investigation was illuminating and will be seen in fig. 106, which shows the relative amounts of energy required (1) to maintain a seconds pendulum

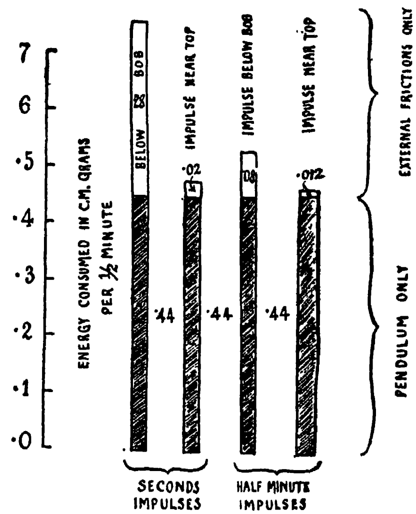


Fig. 106. The energy required to keep a pendulum swinging and the energy absorbed in frictions.

in atmospnere, and (2) to overcome external frictions. The former is shown in the shaded part of the columns and amounts to 0·44 of a centimetre-gram. The latter is shown in the unshaded portions of the columns and tells us what we want to know.

The improvements resulting from (1) applying the escapement near the top of the pendulum instead of underneath the bob, and (2) concentrating 30 seconds impulses into one impulse every half-minute, are remarkable and conclusive. Thus in this great trying out of the Detached Gravity escapement with impulse at zero, these two errors were finally exposed and

condemned, and the first three columns of fig. 106 are their tomb-stones.

But it must not be thought that this period of experiment and research yielded only negative results. It produced at least one real achievement, the disassociation of the impelling and switching function which introduced a time lag, not appreciated then, but destined to contribute materially to the solution of the problem of a Free Pendulum.

When describing Rudd's synchroniser in Chapter VI, and regretting that no commercial career was open to such a clever and effective invention, I added, "Yet it has a little niche of its own in the history of horology, because, by means of it, its inventor achieved the first free pendulum. But that is another story, which will be dealt with in its proper place."

This is the place and the time to introduce my readers to what can only be described as the greatest advance in the science of time measurement which has been made for nearly two centuries.

Had anyone told us thirty years ago that he had made and had working for months an absolutely free pendulum which received its impulse (without asking for it) in the form of a blow of uniform velocity imparted to it as it passed through its zero position, we should have been incredulous.

Yet this is exactly what Rudd did in 1899, the basis of his achievement being a slave clock synchronised by the apparatus illustrated in fig. 20, Chapter VI, but it lacked publicity and the busy world passed it by. It has since been my privilege to present to the Science Museum at South Kensington, Rudd's "No. 2," which the inventor gave me when retiring to the country in 1930.

If our clockmakers and horological professors had understood Rudd's description of it which appeared in the *Horological Journal* of June, 1899, and had believed it, they would have rubbed their eyes and would have

looked regretfully at their library shelves and those ponderous tomes on the theory and mathematics of escapements, back numbers all of them, rendered obsolete by an impertinent invention which dispensed with escapements altogether and impudently imparted an impulse to the pendulum in the manner which their laws pronounced to be perfection, but which they always assumed to be impossible.

I was so fascinated with his synchroniser that when I first saw his Patent (1898), I made a model of it straight away, but I did not come across his Free Pendulum until 1908. In that year I took Mr. (now Sir Henry) Cunynghame down to Rudd's house at Croydon to see it. I remember how difficult I found it to understand his mechanisms; what they were for and how they worked, and my astonishment that he seemed quite unable to explain them through lack of facility of expression. But once I grasped it, this ideal was the star to which I hitched my wagon, and it was never out of my mind during the experimental period above described.

Indeed, Mr. Shortt and I were not far from its realisation in those pre-war days. His persistence in adhering to "impulse and contact every second" demanded an intermediary instrument in the nature of a relay, which we called a time transformer. This was necessary to take hold of 30 successive seconds impulses and to transform them into one impulse every half-minute for the purpose of wholesale and economical distribution of time.

We adopted a half-seconds pendulum synchronised and propelled by means of a one-sided crutch lifted every second by an electro-magnet and operating a count-wheel which released a Synchronome switch every revolution. I saw in this a possible slave clock and forecasted the free pendulum as the clock of the future, in a lecture before the West of Scotland Astronomical Society at Glasgow in November, 1912.

CHAPTER XXV

RUDD'S FREE PENDULUM

IT was in pre-war years that the idea of a free pendulum emerged from the chrysalis stage where it had lain hid since 1899, wrapped up by its parent as carefully as a cocoon is wrapped in silk.

The inventor was R. J. Rudd, and he concealed his babe in the swaddling clothes of two articles in the *British Horological Journal* of August, 1898, and June, 1899. The joke—or the tragedy—of it was that the concealment was unintentional, yet he could not have hidden it better had he been Huyghens burying his discovery of Saturn's rings in a cryptogram to secure his priority, and yet give him time for further research.

He set out with artless simplicity to describe his invention in full, but his outlook was so narrow that he couldn't see the wood for trees; he described his mechanisms without explaining their object, and one doubts whether he realised the possibilities of his own invention or its applications. The titles of his articles, "Automatic Regulation of Clocks," and "Controlling Pendulum for Inferior Clocks" alone reveal his limited vision. Yet in spite of their cryptic nature, the germ was there, the feat was accomplished, and the world was shown that a free pendulum was possible. Not that Rudd's devices have ever been reproduced or used; in this respect we are reminded of Harrison, who did not invent the marine chronometer, which he is popularly supposed to have done, but did something much greater by proving the possibility of measuring time on board ship with sufficient accuracy to determine longitude. To accomplish the hitherto impossible is always the greatest, because the first step; lesser men may perfect the means.

Just as the theory and laws of the Hertzian waves, on which the whole fabric of wireless telegraphy is built, lay hid for years in the mathematics of Clark Maxwell, so Rudd solved the problem of the free pendulum thirty years ago, but lacking facility of expression, he failed to enunciate the principles involved even if he fully understood them himself. He does not appear to have realised that his invention contributed anything to the science of accurate time measurement. He put it forward as a method of improving the time-keeping of a bad turret clock as if to emphasise that his political outlook was confined to the parish pump and that he could not think imperially. Unfortunately, he suffered from the inventor's inability to bring his goods to market, and he was so constitutionally impractical that he would not even avail himself of offers of help.

Figures 107, 108 and 109 are taken from the June, 1899, issue of the *British Horological Journal*. In the description accompanying them, the fundamental facts essential to their understanding are not mentioned. For instance it is assumed that the reader has grasped the idea of a free pendulum altogether detached and presumably at a distance from a clock. Underneath the pendulum there is a storage of power adapted to impart an impulse to the pendulum at wide intervals, such as once a minute, when released by an electro-magnet. The function of the distant clock is to close the circuit of this electro-magnet at the time and phase when the free pendulum is ready to receive its impulse.

When the act of imparting an impulse to the free pendulum is over, the moving part which has accomplished it then transmits a synchronising signal to the clock, thanks to which it is competent to perform the escapement function at the proper time. That is the great fundamental principle of the Free Pendulum, and though Rudd never expressed it in words, I believe that the idea originated with him and that his mechanism was the first to accomplish it. The method of syn-

chronisation is not described, but may be assumed to resemble that illustrated in fig. 20, Chapter VI.

In fig. 107 the lower end of the free pendulum is seen with its impulse face F moving to the left just before receiving an impulse. The impulse will be given by a roller D at each semi-rotation of the lever AA centred at B, when unlatched by the magnet M. In fig. 108, B is seen as a pinion engaging with a gear wheel

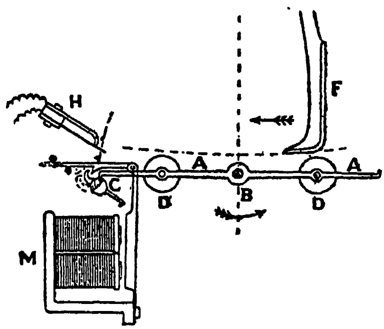


Fig. 107. Impulse to Rudd's Pendulum.

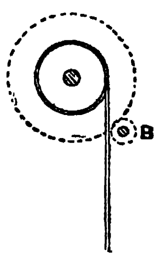


Fig. 108. Weight-drive of Impulse.

on a weight drum. Rudd recommended that the spindle B be mounted on friction rollers "to avoid the use of oil and ensure uniformity in the energy given to the pendulum; none is taken from it." When AA has given its impulse to the pendulum and has nearly completed its semi-revolution it breaks the contact H. That constitutes the synchronising signal and it is to be noted

that its precise point of time is dictated by the free pendulum itself. AA then comes to rest on one half of the arbor C, the other half being cut away.

We are left to assume that the synchronising of the slave clock is satisfactory, and we are told nothing as to the nature of the contact which operates the magnet M. The examples constructed by him were undoubtedly successful, but so far as I am aware, no one else ever made one.

It will be remembered that the subject of synchronisation was dealt with at some length in Chapters IV, V, and VI. Those chapters were devoted to signals at infrequent intervals such as are transmitted hourly or daily from a source of standard time to correct or synchronise independent clocks, whether key-wound or self-wound, and it was indicated that the synchronisation of a slave with its free pendulum would be treated separately, since, though the principle is the same, it differs so widely in its object.

We can easily believe that Rudd's synchronising of the slave clock was adequate since an approximate result appears to be sufficient. An error of only $\pm$s·01 (one-hundredth of a second) in measuring the duration of any individual minute represents quite a considerable error in a longer period, $\pm$ some 14 seconds per day or 100 seconds per week. One of his free pendulums, provided with an unusually heavy bob, received an impulse only once every 4 minutes, and he remarks with unassailable accuracy that if the slave clock strayed to the extent of a minute a week, it would only represent an error of one-fortieth sec. in any individual impulse.

I have been in danger of wearying my readers in my insistence upon the merit of occasional impulses to a pendulum instead of the tick-tock of every swing, but I must yield the palm to Rudd, who proposes quite seriously to give a push to his free pendulum every few hours or so!

It is to be inferred that the accuracy of his slave

clock and its stability under synchronisation is insufficient for such a feat since he proposes to let the pendulum itself unlock the maintenance. He provides a simple device for the purpose, which is illustrated in fig. 109. It is in the nature of an addition to the catch C.

A seconds pendulum will maintain its vibrations for a long time if it has a heavy bob and nothing but air resistance and the flexing of the suspension spring to impede it, and it will still be swinging if left for an hour

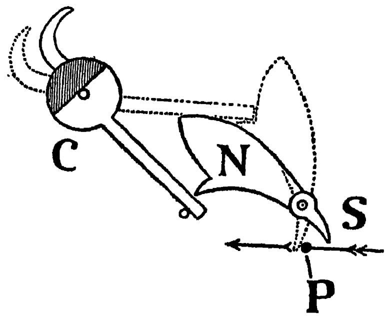


Fig. 109. Rudd's Escapement for long intervals.

or two. The magnet M may now be operated by the slave clock at any time such as once an hour, and the synchronisation need only be good enough to secure that the impulse arrives when the pendulum has passed zero in its excursion to the right and before its return to zero. In this period, that is to say, any time during the last second of the hour, the signal arrives and the magnet pushes up a little trigger N S into the path of a pin P on the pendulum, and lodges the catch C supporting the impulse lever on to the notch N, so that when the pendulum returns to the left, it helps itself to a substantial impulse.

The fact that the pendulum itself is called upon to perform the release takes it out of the realm of free pendulums, and some would say that such rare impulses take it out of the realm of reason, but it gives one

furiously to think. Rudd's invention came at a time when the profession badly needed a "jolt." The British Horological Institute is entitled to all the credit due to its publication in their journal, but it is to be regretted that not one of our famous old firms of clockmakers took hold of it and tried it out. Our Horological Schools are, in my opinion, open to the same accusation of lack of enterprise. The professors would have done well to set the students in every class to make a model of Rudd's Free Pendulum if only for the valuable lessons it would impart and the theories it would illustrate.

Rudd's seed fell on barren soil and ten years elapsed before I found it, and grafted it on to the Synchronome tree, where it was tended patiently for another ten years before the first practical free pendulum blossomed.

CHAPTER XXVI

OTHER FREE PENDULUMS

MY readers may remember that in Chapter X, I mentioned that in the year 1879 the British Association appointed a committee to consider the question of astronomical clocks and that Sir David Gill set out its terms of reference as follows:—

"To maintain the motion of a free pendulum in uniform arc, when the pendulum is kept in uniform pressure and temperature, and to record the number of vibrations which the pendulum performs, is to realise the conditions which constitute a perfect clock."

He made a clock which he thought would fulfil these conditions, but it turned out to be nothing more or less than a "Froment," of whose existence he was unaware. He failed to appreciate the underlying principle and greatest merit of this invention, and consequently met with contact troubles. He took the wrong road in endeavouring to overcome them and wasted his energies in following up the blind alley of delicate contacts produced by radiometer arms in vacuum tubes.

In the early years of this century, during his distinguished career as director of the Cape Observatory, he began again and this time he attempted, with the aid of the Cambridge Scientific Instrument Company, to produce a free pendulum. No satisfactory description of this clock has ever been published, and no illustration of it exists, so far as I am aware, but I quote from Sir David's official report dated February 1st, 1904, as follows:—

> The clock consists of two separate instruments: (*a*) a pendulum (swinging in a nearly airtight enclosure,

the air in which is maintained automatically at uniform temperature, 30 degrees C., and low uniform pressure, 30 millimetres); (*b*) the "slave clock" with a wheel train and dead-beat escapement, the pendulum of which has a period of vibration slightly shorter than one second. This pendulum is "held up" by a trigger for about a tenth of a second at each alternate beat, and this trigger is discharged by the short-circuiting of its electro-magnet through the gravity arm of pendulum *a* at the instant when this arm is arrested by touching the platinum anvil that limits its fall. The "slave clock" shows the minutes and seconds and makes the electric contacts necessary for raising and liberating the gravity arm of the main pendulum at the proper instants. It also makes the electric contacts for the chronograph and the contacts connected with the automatic control of temperature and pressure. The impulse given to the pendulum depends on gravity only, and is entirely independent of the effects of any sticking or repulsion at the points of electric contact.

In the Report of the Observatory for 1905 it is mentioned that some trouble occurred due to residual magnetism in the electro-magnet which discharges the pendulum of the "slave clock" at each alternate second; and in the Report for 1908 it is stated that the clock proved to be unreliable, mainly on account of electrical faults, and that it had not been found possible to bring it into regular use, but that there were signs that the difficulties had been overcome.

In the meantime, however, Sir David Gill retired, and the Admiralty refused further expenditure upon costly and unprofitable experiment, so the story closes with an announcement in the 1911 Report that a new clock, with airtight case and nickel steel pendulum, by Riefler, of Munich, was purchased and installed in the clock-chamber.

To Sir David Gill belongs the credit for coining the word "slave clock" and for putting the free pendulum in a vacuum, but in all other material respects he went astray. The accursed custom of impulse every second had him tight in its clutches, and it is interesting to speculate what would have happened had he met with Rudd, who gave his free pendulum an impulse once a minute, once in four minutes, or once an hour.

From the description above quoted, it appears that the impulse was given by a gravity arm as in the Steuart clock illustrated in fig. 45 in Chapter XI. The arrival of the gravity arm on its stop constitutes the synchronising signal in both clocks, but Steuart's continuously running motor is a better slave than Sir David Gill's dead-beat escapement clock.

The next attempt was by Mr. C. O. Bartrum, of Hampstead, in 1913. His free pendulum was a distinct advance upon his predecessors since he applied the Synchronome detached gravity escapement with impulse at zero to drive it and operated it once a minute, using the Synchronome remontoire as his synchronising signal to control a Graham dead-beat escapement clock as his slave, but as is so often the case with those who only see in it a convenient method of replacing a lever when it has fallen, he lacked true understanding and appreciation of its merits. He added springs to prevent "chattering," and to ensure "saturation," but they are unnecessary with regard to the former, and if effective in achieving the latter, they would rob the switch of some of its greatest virtues.

Each signal is shunted to a fasting or slowing magnet 9 or 10, as shown in fig. 110, operating on the capstan 15, in the manner described in my paper before the Institution of Electrical Engineers in 1910, and illustrated in fig. 23 of Chapter VI. But instead of raising and lowering a collar weight on the pendulum as in mine, a silk cord 17, 18, wound on the capstan's drum controls the rate of the slave by means of a spiral

spring attached to its pendulum. As the signal does not correct or "set" the clock, this arrangement would merely rock the error, as I have so often explained, and instead of adopting the direct method he adds a supplementary spring, applied by lever 20 and cord 23, 24, by means of which an additional correction of a fixed amount is superimposed which, unlike the capstan correction, has no cumulative effect.

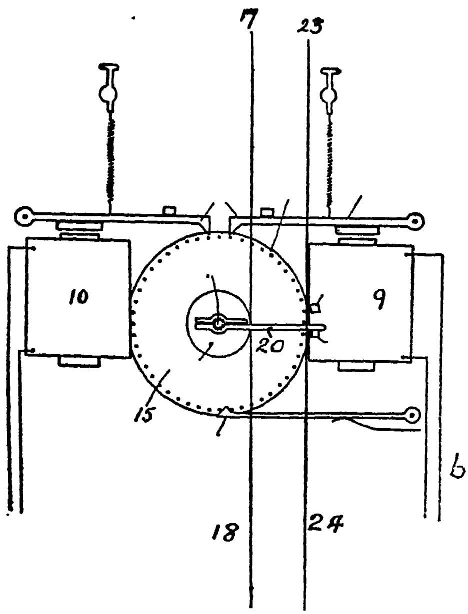


Fig. 110. Mr. Bartrum's Synchroniser.

The contact on the slave which enables it to perform the escapement function for the free pendulum is, in my opinion, too indefinite for such a purpose, lacking in precision of its time-spacing and in the cleanliness of the make and break. It is taken from a wheel specially provided for the purpose in the same plane as the pendulum, and propelled by it one

tooth at each complete vibration. The wheel carries a pin on its periphery which elbows its way between two springs in the manner of Campiche, shown in fig. 78 of Chapter XVII. The indictment against this sort of thing was ably drawn by General Ferrié in the October, 1929, issue of the Monthly Notes of the Royal Astronomical Society, and in the following issue I pointed out the straight and narrow way, which was, of course, the use of that other vital Synchronome principle of taking the contact direct off the pendulum itself without interfering with it.

Bartrum does not tackle the barometric error and could not put his free pendulum in vacuo without reducing the Synchronome switch energy to an impracticable amount. The releasing contact must of course be made by his slave clock about $\frac{1}{4}$ second before the remontoire contact of the free pendulum occurs, hence the function of the slave clock should be described as measuring intervals of $59\frac{3}{4}$ seconds; he provides for this—the odd $\frac{1}{4}$ second—by a flywheel inertia device.

That is the best way of expressing the whole principle of the employment of a slave clock to perform the escapement function for a free pendulum. Assume that the impelling lever, whether rotary as in Rudd, or a Bloxam-Grimthorpe gravity arm as in Gill and Steuart, or a Synchronome switch arm as in Bartrum, transmits its synchronising impulse immediately its job is done, then, having decided what interval of time is to elapse before the next impulse is to be given to the free pendulum, the function of the slave clock is to measure that interval *minus*, say, one-quarter of a second or whatever time may be absorbed in the act of imparting the impulse.

In 1918, Father William O'Leary, S.J., of Dublin, dispelled the foggy atmosphere that seems to have shrouded previous inventors, by the clear exposition given in his Patents 2887 and 19007, and his simple mechanical method of performing the feat.

He made his slave out of an old alarm clock. It is given a gaining rate, and I illustrate it in fig. 111, taken from his first Patent. The gravity lever C carries an impulse roller E on its extreme left end. N is a lever centred at M, normally supported upon the minute

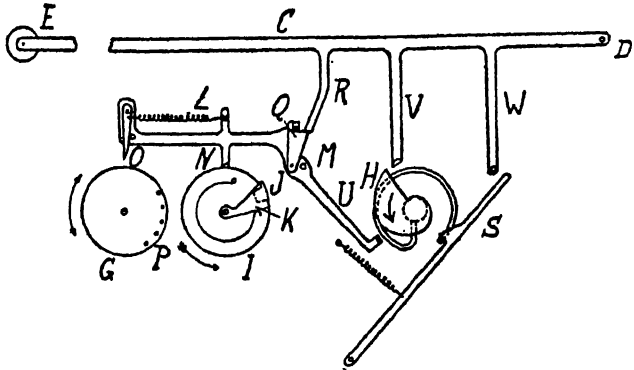


Fig. 111. Father O'Leary's Slave Clock.

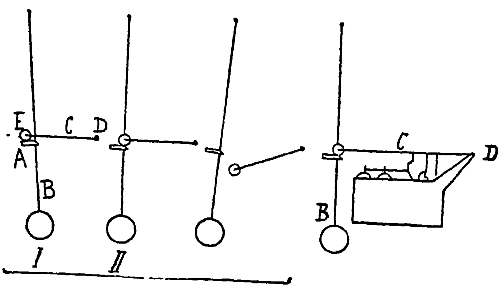


Fig. 112. Father O'Leary's Free Pendulum.

wheel I. When the end of the minute is approaching, N removes the mask K and drops into the slot J, resulting in the following interesting series of happenings.

The spring pawl O drops between any two of the pins P on the balance wheel G thus instantly stopping the clock. Q is removed from strut R and allows the gravity lever C to fall with its impulse roller E on the

dead surface of the pallet A on pendulum B illustrated in three positions in fig. 112. Having given the impulse to the pendulum, C falls freely, the strut W strikes S and

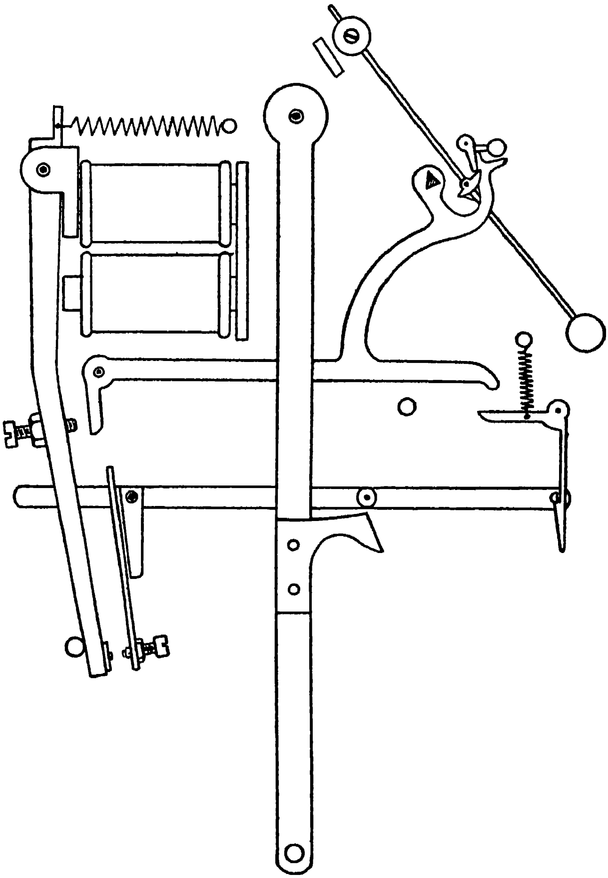


Fig. 113. Parsons and Ball's Free Pendulum with impulse every 2 secs.

releases a separate power train ending in the cam H which engages U and V and quickly starts the clock again, replaces Q under R and re-sets the gravity arm C thereon.

As the slave clock cannot start on its job of timing

the next impulse until the free pendulum has completed its true period, it is in this way corrected every minute by the pendulum. Thus O'Leary makes no attempt to

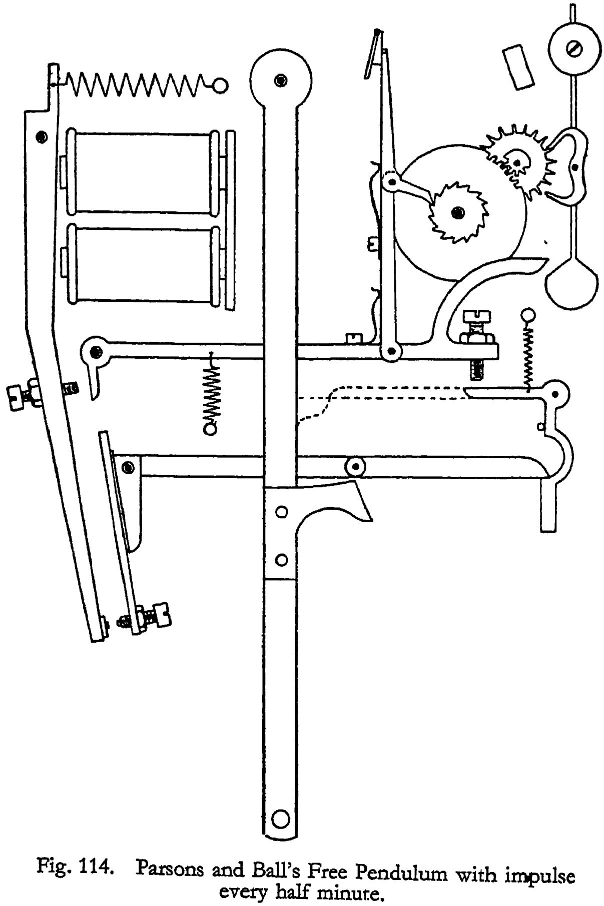


Fig. 114. Parsons and Ball's Free Pendulum with impulse every half minute.

correct the going rate of the slave to make it synchronous with the pendulum, but, giving it a permanent rate as Gill did with his dead-beat escapement clock, and Steuart did with his continuously running motor, he stops it at the end of its shortened period and simply wipes out

the gain by not allowing it to start until the free pendulum says "go."

Messrs. Gent & Co., of Leicester (I. H. Parsons and A. E. J. Ball, Patent No. 160204, 1919), accomplished the equivalent of O'Leary, but rendered it self-winding by the use of the remontoire. Figs. 113 and 114 will not require a detailed description for those sufficiently interested to trace out the action; suffice it to say that the switch is inverted, the armature being pendant. O'Leary's lever C is here represented by two levers, both of which are re-set by the armature, the lower one being the main storage of energy to be imparted to the pendulum and the upper one driving the slave clock (or "time element" as they call it) in its fall and finally releasing the impulse lever.

But the time-keeping of these slaves can hardly be considered good enough even to measure the small time intervals involved, which are:—

> Fig. 113, two seconds minus a fraction, timed by the old verge balance of the fifteenth and sixteenth centuries, before Hooke invented the balance spring, and
>
> Fig. 114, thirty seconds minus a fraction, timed by an alarm clock bell hammer escapement.

These methods are doubtless intended merely to illustrate the idea, and better time measurers could be devised but most of these inventors, recognising the difficulty of the perfect timing of their releases, hanker after the use of the free pendulum itself to determine its precise instant, but if they do so, then the pendulum ceases to be absolutely free. Rudd and O'Leary provided this, and its equivalent in Gent's method is here seen in fig. 114 in the dotted lines on the right of the pendulum.

I have now reviewed in chronological order the only free pendulum inventions known, viz., Rudd, Gill, Bartrum, O'Leary and Gent. So far as I am aware, none of them have been tried out or manufactured for

sale, and whilst it has been my duty to be critical, I ought to add that they represent ingenuity and ability of no ordinary kind, far beyond that called for by the average electric clock invention.

CHAPTER XXVII

THE HIT-AND-MISS SYNCHRONISER

IN Chapter XXIV we were recounting Mr. Shortt's experimental work in association with the Synchronome Company. Its progress was interrupted by the war, and we also broke off at that point into a review of other attempts at Free Pendulums, the work of five inventors who were all unknown to each other and with one exception remained in total ignorance of each other's efforts. They cover the period we are engaged upon, and in order to preserve chronological sequence, we dealt with them in the last two chapters as follows:—

Rudd, 1898-9.
Sir David Gill, 1904.
C. O. Bartrum, 1913.
Father O'Leary, 1918.
Parsons & Ball, 1919.

So we will now revert to Mr. Shortt's improvements upon the Synchronome Detached Gravity Escapement with impulse and contact at zero, which we left at that stage where he was confronted with two apparently insuperable obstacles: (1) "scaping" below the bob of a pendulum, and (2) at seconds intervals.

Fortunately he did not stop there, but ultimately found a way out of the blind alley formed by these impossible conditions. The mechanical release of a Synchronome remontoire under the bob every second or even every two seconds, absorbed too much energy, even when the mass of the gravity arm had been reduced to such a point that it was no longer serviceable as a switch and had to be used to release a heavier one, and the

demand for some other means of performing the release became insistent. Now the division of the two functions, impulsing and switching, and the employment of a

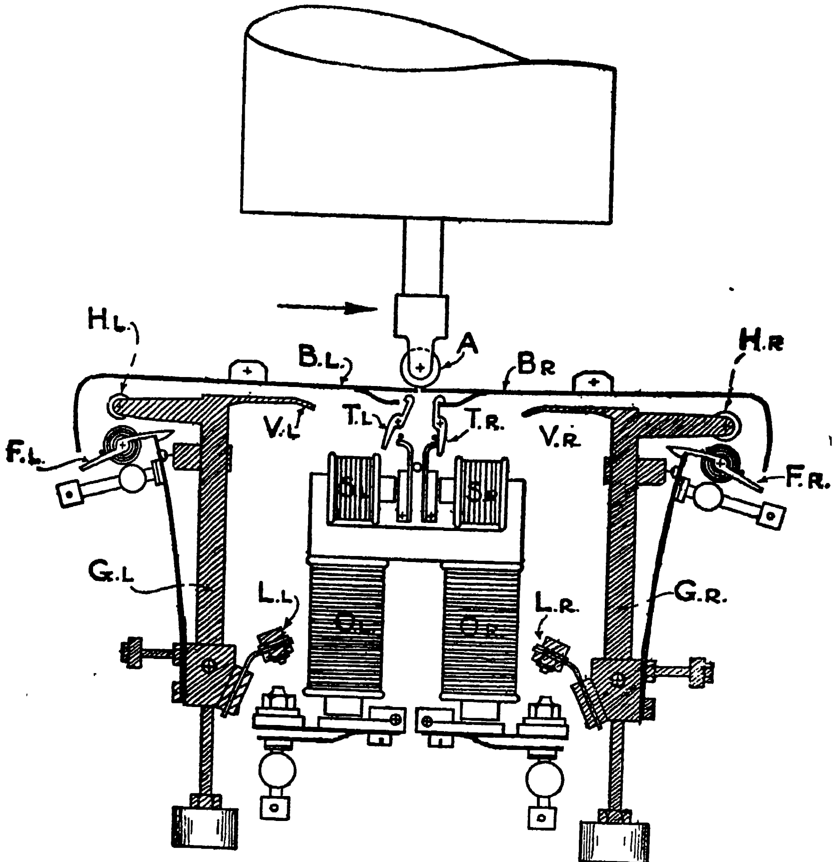


Fig. 115. This diagram of Mr. Shortt's first Free Pendulum shows how he made use of the time lag resulting from the employment of two levers to act as a slave.

separate lever for each, involves a time-lag of considerable duration, sufficient to enable one to look upon the combination as a kind of slave clock capable of measuring the interval between one impulse and the next and

performing the escapement function. Fig. 115 shows how this was done.

The interval between the release of the impulse lever and the re-setting contact is made up of two portions, the first being the time taken by the impulse lever to run down the edge of the wheel and release the re-setting lever, and the second the time taken by the Synchronome remontoire which incidentally re-sets the impulse lever during its operation.

The total value of these two intervals in the case of a seconds pendulum is of the order of three-quarters second, so the final contact can be used to release the impulse for the next second.

The impulse wheel A is mounted on the bottom of the pendulum and swings to and fro immediately above the extremities of the over counterbalanced impulse levers B.L., B.R.

Instead of the pendulum engaging with releasing catches, it is absolutely free, and the releasing catches T.L., T.R., are arranged to be operated by small electro-magnets S.L., S.R., these magnets operating the catches of the right and left hand levers being connected respectively in the circuits of the re-setting magnets O.L., O.R., of the left and right hand levers, G.L., G.R.

Assuming the pendulum to be at the centre of its swing and moving towards the right, the right hand lever B.R. will have just been re-set, consequently the left hand lever B.L. will have just been released and its extremity will be pressing against the under side of the impulse wheel.

As the pendulum continues its swing to the right, the left hand lever will give impulse to the pendulum, on completion of this it will trip the catch F.L. and thus release the Synchronome switch arm which will rotate in a clockwise direction, re-set the impulse lever, and finally make contact with the left hand electro-magnet armature, which will result in its being itself re-set. Further, the making of this contact will also result in

the release of the right hand impulse lever, by means of the catch T.R.

It was found necessary to make the upwards thrust of the impulse levers extraordinarily light, otherwise the impulses, being given so frequently as once per second, were excessive and gave the pendulum too large an arc, which cut down the time interval between release and re-set and resulted in excessive run of the impulse wheel on the dead face of the levers. Yet the impulse levers had to be heavy enough to release the catches of the re-setting levers, and these catches had to be given sufficient spring tension to ensure reliability.

The attempt to reduce these forces led to trouble all round and thus the truth of the old lesson was demonstrated again, that even apart from releasing frictions, the impulse force must be large enough for human hands to handle, and must therefore be 30 or 60 times that appropriate for administering every second. What a long and tiresome process was the learning of this lesson! What years of patient endeavour were needed to overthrow the hide-bound custom of giving an impulse to the pendulum at every second!

It is easy to see now that the invention of the half-minute electric time transmitter in 1905 and 1908 should have been accepted as a final demonstration of the benefits of impulse and contact every half-minute, instead of which a long series of analytical investigations was carried out to demonstrate step by step the impossibility of seconds impulses.

Mr. Shortt's previous experimental analysis had proved that it was wrong to attempt the release of a detached gravity escapement every, or every other second. He now carried this proof a step further by demonstrating that even when the pendulum was altogether relieved of the duty of accomplishing the release it became mechanically impossible to impart impulses to it every second, owing to the smallness of the forces involved.

The electrical aspect of the problem has already been dealt with in the chapter on Transmission of Energy through the Surfaces of the Contact, *i.e.*, Chapter XVIII, which revealed how essential it was to adopt occasional impulses to produce a substantial switch.

That factor was highly important, but was not considered sufficient in itself, and not until the same conclusion was arrived at from the horological point of view did Mr. Shortt seriously seek for a method of

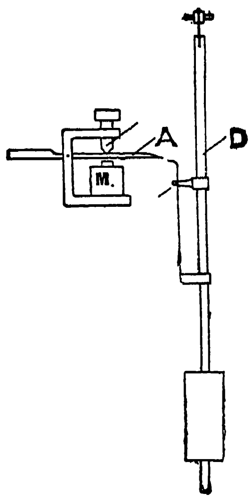


Fig. 116. Showing the operation of Mr. Shortt's "hit and miss" synchroniser.

measuring longer intervals, a method involving the synchronising of a slave clock and employing that clock to perform the escapement function. The delay was disappointing, since I had already attempted to use the synchronous half-seconds pendulum of the time transformer referred to at the end of Chapter XXIV, for the long-period releasing of a free pendulum, but I had not then investigated the effects of applying a half-minute electro-magnetic impulse to a half-seconds pendulum, a subject subsequently dealt with in my Paper before the

British Horological Institute in November, 1929, and the attempt did not succeed.

Fortunately, Mr. Shortt hit upon a much better means of making two pendulums swing together in precise sympathy, viz., the "hit-and-miss synchroniser," which enabled the coupling together of two Synchronome clocks, so that one, the slave, would accomplish the release of the gravity arm of the other, the master. He placed a vertical leaf spring L on the pendulum D, fig. 116, and a horizontal armature A pulled downwards by an electro-magnet M in the half-minute circuit of the free pendulum's remontoire. The slave pendulum D was given a small losing rate so that when the point of the vertical spring was late in arriving at armature A, it was caught and deflected, thereby quickening that semi-vibration, since the spring adds to the force of gravity. Its tension is such that it effects twice the amount of the correction necessary, with the result that the engagement will take place approximately at every other swing, hence the term "hit-and-miss."

This was entirely original with Mr. Shortt, and he secured a patent for it dated 30th September, 1921, but Mr. W. S. Hubbard (jointly with Messrs. Parsons and Ball) had already applied for a patent (June, 1920), which contained the same root idea, the armature taking the form of a rack with a view of varying the amount of synchronisation.

I rank this invention as one of the very few of outstanding importance in the applications of electricity to horology, and the first man to conceive it was undoubtedly Mr. William Sammons Hubbard, of Leicester. An earlier Patent, No. 160,988, of 1920, taken out six months before, appears to be the stepping stone which led to the final solution, and I reproduce in fig. 117 an illustration from it.

The pendulum A carries an armature B on the end of a spring B2. The magnet C is in a half-minute time-circuit, and is so placed as to be just over the armature

when the pendulum is at or near the end of its swing to the left. If the pendulum is fast, it will be returning when the half-minute impulse arrives, and checked and delayed by friction when the armature is gripped, and if the pendulum is slow, the check it receives will

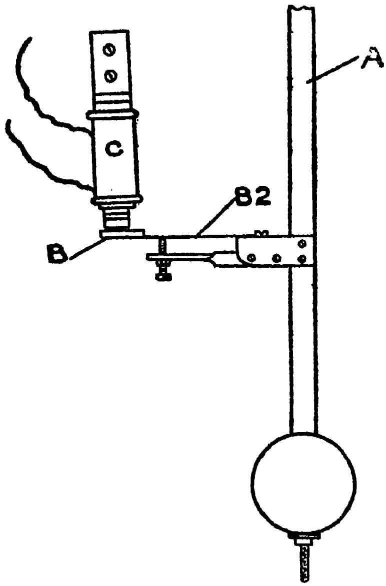


Fig. 117. An early form of Mr. Hubbard's Synchroniser.

quicken it. The circular error doubtless has a considerable share in the synchronising process, but the inventor makes no mention of it.

His next Patent (No. 167,060), in association with Messrs. Gent & Co., of Leicester, has, I hope, enabled him to reap his reward in the commercial application of the idea, represented by the "Reflex" control of time recorders. In fig. 118, A is the leaf spring on the pendulum B of the slave clock, and D the electro-magnet in the half-minute circuit. The sloping end of the armature C1 is provided with saw teeth with the happy result that the amount of correction will be

proportionate to the error since the engagement may take place earlier or later.

Mr. Shortt, on the other hand, in his Patent, No. 187,814, relies entirely upon the "hit or miss" action

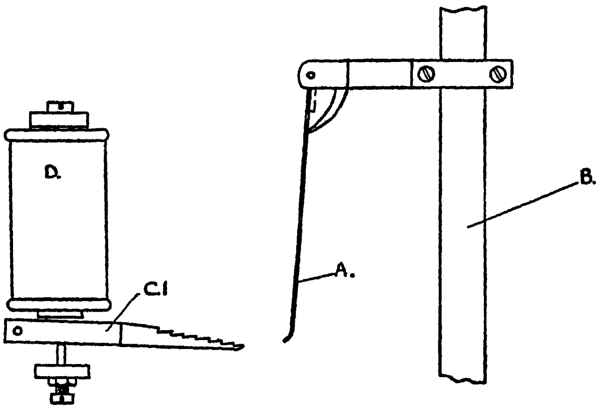


Fig. 118. The "Reflex" synchroniser of Messrs. Hubbard, Parsons and Ball, the application of which has been commercialised.

for synchronising, since in the free pendulum there is merit in imparting a correction of a fixed and definite value whenever required.

This was the last thing needed to produce a practical free pendulum, since it enabled two Synchronome clocks to be firmly held in synchronisation.

The first one was erected by Mr. W. H. Shortt, M.Inst.C.E., in the Edinburgh Observatory, with his own hands, at Christmas time, 1921, the free pendulum itself being in a cylindrical copper case from which the air was exhausted. It is known in the astronomical world as SH.O, and the report of Professor Sampson upon its first year's run created a sensation.

Its movement is fairly represented by one half of our fig. 115, its impulse being delivered upwards under the bob, but the magnet S is in the half-minute circuit of an ordinary Synchronome standard master clock provided with a hit-and-miss synchroniser.

Fig. 119 is a diagram showing the electrical connections of a free pendulum and a slave. For the sake of simplicity, the double remontoire used for impelling the free pendulum is not shown. That was illustrated

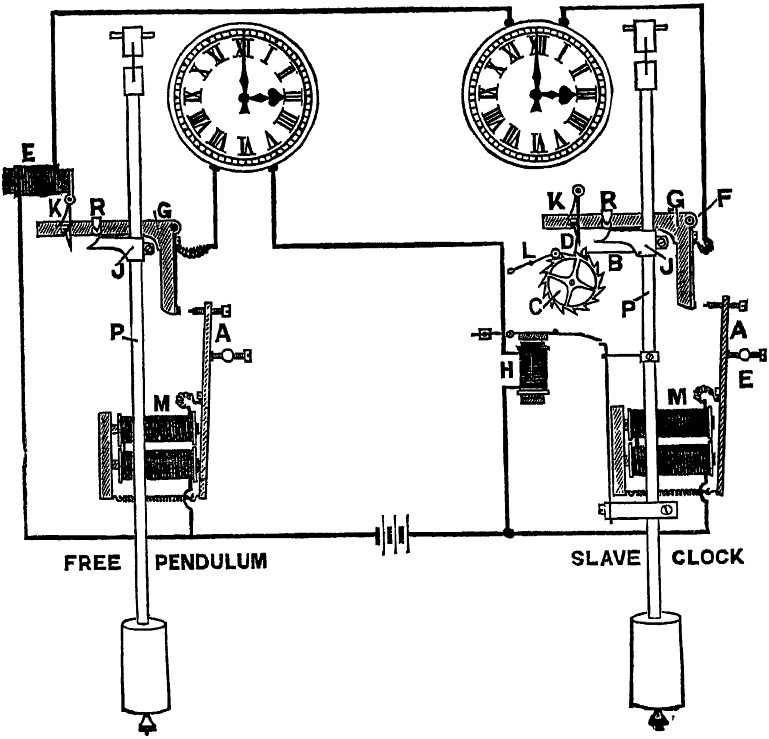


Fig. 119. The Synchronome Free Pendulum, showing the electrical connections of a free pendulum and a slave.

in fig. 105, Chapter XXIV, as well as in fig. 115 above, and provides the time lag necessary to preserve the difference in phase between the two pendulums, it being observed that the act of comparison occurs when the free pendulum is well past zero on its passage to the right, and the slave is at zero on its passage to the left.

This diagram will be easily understood if it is realised

that the slave clock on the right is an ordinary standard Synchronome master clock, and includes in its circuit the electro-magnet E, which consequently releases the free pendulum's gravity arm every half-minute. When the free pendulum's Synchronome switch or remontoire operates, it includes the hit-and-miss synchronising magnet H, thereby keeping the slave in phase.

CHAPTER XXVIII

THE SYNCHRONOME FREE PENDULUM

CHAPTER XXVII saw the fulfilment of the promise I made in the introduction that I would describe the Free Pendulum. I need not apologise for having taken two-thirds of this book to carry out my pledge, since it has been necessary to lead up to it by a review in chronological order of most of the inventions in electric clocks of which anyone has ever heard.

It is astonishing what a large number of these inventions have turned out to be futile, but I have described them all because there are lessons to be learned from failures as well as from successes. It has in fact been my aim to be analytical and critical, to distinguish between good and bad, to find reasons for the disappearance of those that have faded out and, above all, to recognise intrinsic virtues wherever they existed.

The successful free pendulum is based upon the use of certain fundamental principles whose origin and importance have been revealed during this process of review. An entirely new standard of accuracy in time measurement has been set up, and I propose in this chapter to reconstruct before your eyes the clock that has achieved it, using these principles as our building materials.

Who first conceived of the idea of a free pendulum? That is to say, a pendulum which synchronises another clock and uses that clock to perform the escapement function for it? The answer is R. J. Rudd, in 1898.

He expressed himself in mechanism rather than in words; he gave no reasons, he enunciated no principles, but he made a free pendulum which worked, and some of the means he adopted were fundamental essentials; for instance

(1) he gave the impulse to his pendulum rarely, such as once a minute, instead of every second or every other second. He appears to have had no particular reason for so doing, except the obvious one that his pendulum did not require more.

(2) He delivered the impulse to the pendulum when it was more or less at zero, and

(3), the arm which delivered the impulse, having completed its job, transmitted a synchronising signal to the slave clock.

One always regrets that Rudd's invention which contained these three essentials was never tried out and developed. Whoever did so would be up against the necessity of improvements in

(*a*) the impulse, since Rudd's rotating arms involved storage of power in a train of wheels which, however short and frictionless, could not be as constant as a single lever, and in

(*b*) a more reliable and perfectly timed contact in the slave clock, to release the free pendulum's impulse.

With regard to the others, Sir David Gill lacked Nos. (1) and (2). He had No. (3), which gave him a precisely timed contact, but it was worthless, since it lacked energy.

Mr. C. O. Bartrum had (1), (2) and (3), but, like Rudd, he was deficient in (*b*).

Father O'Leary and Messrs. Gent had (1), (2) and (3), (mechanical) and the difficulty (*b*) did not arise, since their release was mechanical, but it was not good enough.

The successful free pendulum, known to astronomers as the Shortt Clock, has (1), (2) and (3), since these features are fundamentally in the Synchronome switch, and some further comment upon them is desirable.

(1) *Occasional impulse* is demanded by two considerations of overwhelming importance. First, the giving of an impulse to a pendulum, however careful

we may be in the mode of delivering it, and the precise point in the phase of its vibration at which we impart it, is nevertheless an *interference*. The less time this operation takes relatively to the total time measured the better, and the more the pendulum is free. In the Synchronome Free Pendulum, it is in the ratio of one in 100; in ordinary escapement clocks, it may be anything from 50 in 100 to 100 in 100, as in the Grimthorpe gravity escapement where the pendulum is never free. It is no answer to say that the same amount of energy has to be imparted in any case, viz., that which is necessary to maintain the vibrations of the pendulum at the arc desired. The suggestion that 30 small instalments are as good as one of 30 times the value will not hold, as I emphasised in Chapter XVIII.

Secondly, since it is essential that no energy shall be taken from the free pendulum for the purpose of making contact, it follows that the Synchronome switch shall be used and one of the peculiar merits of that device is that the whole of the energy required to drive the pendulum (that is to say, the energy required to replace the gravity arm) is transmitted through the surfaces of the contact. As explained in the above chapter, this energy, for the purposes of a reliable switch, is worth its weight in gold, and we therefore multiply it by 30 by making the lever heavy enough to require its use only once every half-minute. Even then the energy is not sufficient for our purpose, so when the lever has delivered its impulse to the pendulum we call upon it to release a far heavier lever loaded with considerable mass, so that when it falls into contact it does so with a pressure which cannot fail.

(2) *Position of impulse*. Fig. 120 shows how the half minute impulses are imparted to the free pendulum. The gravity arm G^1 carries a jewel R at its free end, and J is the impulse wheel on the pendulum which receives R when it falls. The lever G^1 is released by the slave as the pendulum, and therefore the wheel, is

approaching zero from the right and the wheel is not always in precisely the same position when the jewel falls upon it. But the impulse always begins before

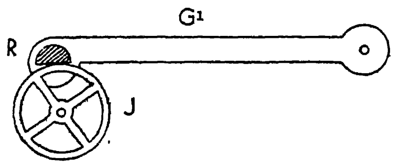


Fig. 120. Impulse to Free Pendulum.

zero in exactly the same place and begins with extreme gentleness in the descent of the jewel on the periphery of the wheel, and it finishes after zero at a point determined by gravity alone, since it drops off the wheel as described in the *British Horological Journal* of January, 1906.

(3) *The Synchronising Signal.* This is one of the most important and most ingenious of the inventions which have made the free pendulum possible. It always puzzles a layman, and even the technical horologist, to understand how a free pendulum, which is really free and is not permitted to make an electrical contact, can communicate a synchronising impulse to a slave clock. The explanation of the apparent paradox lies in the fact that the free pendulum receives its impulse from a falling lever or gravity arm, and that whilst the point of time at which the lever falls on the impulse pallet is dependent upon the ability of the slave clock to measure the intervals with precision, the time at which the impulse is completed is dictated by the free pendulum itself, and is communicated to the slave by means of a synchronising signal resulting from the falling away of the lever after the impulse is finished.

The free pendulum accepts whatever error there may be in the time at which R falls on J (fig. 120), and corrects it by absorbing any difference whilst the flat underside of the jewel is on the top of the wheel.

In order to enable the cycle of operations to be followed in their precise sequence, I have re-drawn in fig. 121 the diagram which appeared as fig. 119 in the last chapter.

Looking at the free pendulum on the left, two levers, G^1 and G^2 will be observed, each performing

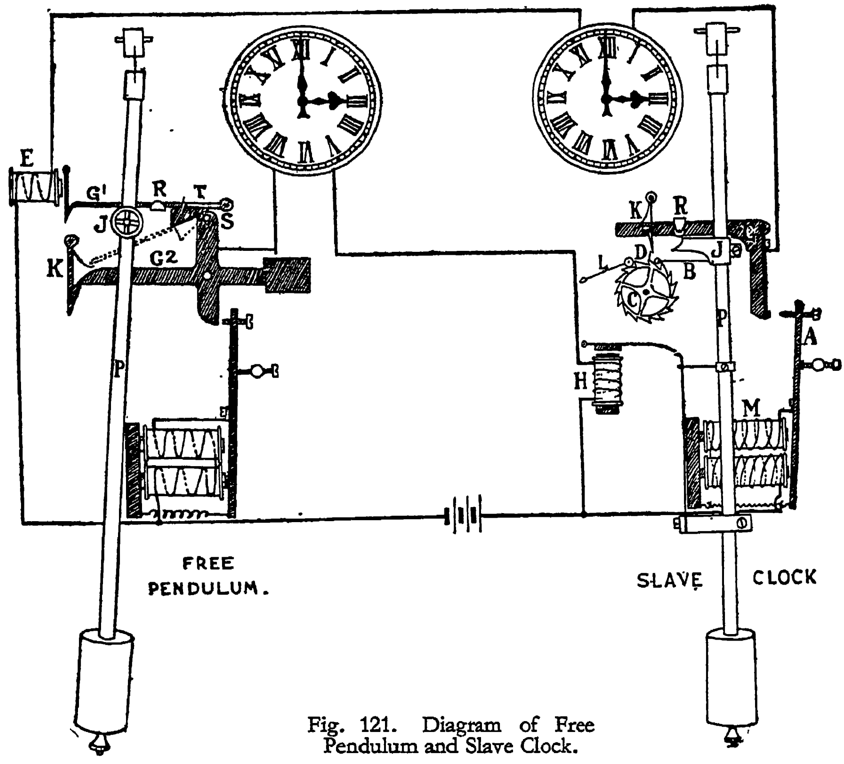


Fig. 121. Diagram of Free Pendulum and Slave Clock.

its separate duty of (G^1) impulsing, and (G^2) switching, thus disassociating the two functions usually performed by one lever in the Synchronome switch.

When the slave clock operates magnet E and releases G^1, the free pendulum is on its way to zero on its excursion to the left. The jewel R having fallen

more or less on the top of wheel J, the impulse begins with extreme gentleness when the left hand corner of the jewel R runs down the periphery of the wheel J and terminates when it drops off the wheel. G^1 then falls upon the wing of catch K and releases the switch arm G^2 which, in falling, gently replaces the impulse lever G^1 on to its catch by means of the arm S and cam T.

The considerable time which elapses between the release of G^1 by magnet E and the operation of the remontoire which replaces G^2, can now be realised, and it amounts to about eight-tenths of a second, during which period the slave pendulum, which was a little beyond zero on its excursion to the right, completes its swing in that direction and returns to zero in time for the *act of comparison* which determines whether or not *correction* is required. I state it as a law that comparison should take place at zero, in order to secure accuracy, just as impulsing must, in order to secure minimum disturbance. On the other hand, correction should be effected whilst the pendulum is swinging out and home in order to obtain maximum disturbance.

Thus the slave pendulum measures just a very little more than 29·2 seconds of time and the subsequent operations absorb the remainder of the half-minute. The excess of the first period over 29·2 secs. varies within the known limits permitted by the hit-and-miss synchroniser, usually of the order of one-twohundredth of a second. The second period is mainly absorbed by the free pendulum's impulse and remontoire mechanism, and is a little less than 0·8 sec. Whatever it is, it is constant if the arc is constant. These two periods may be said to *overlap*, the amount of the overlap being represented by the difference in the relative positions of R and J when the release takes place, and the correction is therefore made by the free pendulum itself, since the position at which the impulse begins is invariable. The variation of the amount of the lateral

run of the dead flat underside of R on the top of the wheel J is something less than ·01 mm.

In dealing with such extremely small quantities of time and space, it is essential that the electrical contacts derived from the two pendulums must represent their time precisely. For such purposes, contacts applied to wheel-work would be altogether too uncertain and irregular. In the case of the slave clock, for instance, it would be futile to put a pin in the periphery of the 15T wheel to engage a spring in passing.

CHAPTER XXIX

THE PRINCIPLES OF THE FREE PENDULUM

THE horological text-books are full of information and advice as to how to build precision clocks, but most of them forget to remind us of the principles underlying their construction.

They discuss escapements in detail and frequently with enthusiasm without confessing as they should on every page that escapements involve almost continuous interference with the pendulum, and they are at best an unsatisfactory means of impelling it. The science of horology may be said to exist to mitigate these evils, but you would never think so from reading books on clockmaking, since they rarely mention them.

As recently as the year 1920, a correspondent in the *British Horological Journal* asked for "the best specification of a seconds pendulum clock capable of keeping the closest rate, and whether it should be electric." He was given the following answer:—

> "Barrel, 2 in. diameter; great wheel, 168; centre wheel, 120; third wheel, 98; 'scape wheel, 30. Pinions of 14, all hardened and tempered, escapement, Graham dead-beat, embracing eight teeth. Pallets, jewelled sapphire. Mercurial pendulum. Suspension spring, short, broad and thin. Maintaining power must be fitted. Line to be of silk, and, if possible, carried over loose pulley to hang down side of case. Jewel holes should, for preference, be supplied to 'scape wheel and pallet holes. *We do not advocate an electric clock for this purpose.*"

Faultless advice, endorsed by all the best clockmakers in the profession up to the beginning of this century, but not quite up-to-date, in so far as it ignores Riefler, perhaps on the ground that his construction would be

beyond the powers of the ordinary clockmaker. And a little behind the times with regard to the pendulum, which should, of course, be of Invar, and with regard to the weight-driven train, proved to be unnecessary not so much by the Synchronome invention of 1895 as by Riefler's adoption of it when the German patent ran out.

This incident serves to remind us of what we may call the official attitude to electric clocks up to a few years ago. It also serves to remind us how the clock-making profession had accepted the weight-driven regulator with the Graham dead-beat escapement as being the last word in precision time-keeping and how escapements have dominated horology for two hundred years. We have never been able to get away from them, our orbit has been bounded by them, and they have produced a mental atrophy which has blinded us to the possibilities of doing anything better.

In a man, it is his principles that count; his character is built up of them. So it is in the free pendulum clock we are describing. Let us avoid absorption in details of wheels, pinions, and escapements, and devote a chapter to Principles. They are the real building materials used in its construction.

It is not easy to give them an order of relative importance, since they are all vital, but we may select as our foundation stone *the transmission of energy through the surfaces of the contact.* The stone which the builders refused is become the headstone of the corner. Froment, whose contact device first contained it, was unaware of his achievement or its merits, and the horological Press of two continents has ignored it, yet the use of this principle gives us a reliable contact without taking any energy from the pendulum.

Perhaps next in importance is the *control of the duration of the contact by self-induction*, resulting in compensatory action and all the blessings which flow from it, such as battery warning, the uniform wave shape of every

impulse, and the security that every electro-magnet in the series circuit shall develop the ampere-turns necessary to enable it to do its work.

Then we have the *sailing into contact at the speed of the moving pendulum*, quick enough to ensure that there is no preliminary sparking, yet not quick enough to cause a bounce; and the *momentum break*, the cleanest and most rapid method of separating a contact that one could wish for.

Other useful bricks are the *exactitude of the timing of the contact*, the *impossibility of stopping in closed circuit*, and the *facility for advancing a group of electrical impulse dials* in minimum steps of two seconds.

Then there is that stately group of purely horological masonry, the site for which was cleared by the demolition of the clock wheels and escapements entangling and interfering with the pendulum all the time.

Its foundation stone is the Synchronome remontoire with its *detached gravity escapement*, provided by a constant weight falling a constant distance *every half-minute*, giving uniformity of impulse imparted with extreme gentleness at first, then growing in its force until reaching its *maximum at zero*, and diminishing in equal ratio immediately thereafter. Also the concentration at the zero position of such other interferences as exist and the *freedom of the pendulum* at the end of its swing.

Such were the materials which were used in the construction of the Synchronome master clock, or electric time transmitter, and at this stage we may expand our metaphor to bring in Mr. W. H. Shortt as the master builder who added the keystone to the arch by connecting two of them with his synchroniser, thus freeing one pendulum altogether and enabling the other to perform its escapement function for it.

The application of these principles has reduced the external frictions to the absolute minimum, and the stages in the process are well illustrated in fig. 122, a diagram prepared by Mr. Shortt on the same lines as

fig. 106, Chapter XXIV, which represents the relative amounts of energy required (1) to overcome the external frictions, and (2) to maintain the vibrations of the

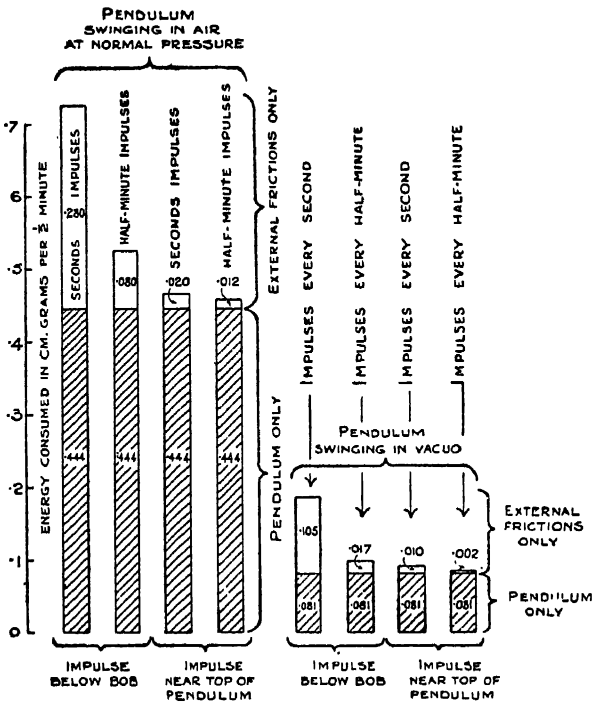


Fig. 122. Energy absorbed by Pendulum.

pendulum against air resistance and flexing its suspension spring.

It will be seen from the left-hand half of the diagram that when the pendulum is swinging in air at ordinary pressure, the worst arrangement is to deliver an impulse below the bob every second; that considerable improvement is effected by reducing the frequency of the impulse to one every 30 seconds; and still further improvement by giving the impulse near the top of the pendulum.

When the pendulum is swinging in vacuo the effects are even more pronounced, owing to the reduced amount of energy required by the pendulum itself and the greater relative importance of external frictions.

The last column on the right shows that almost the only impediments remaining are the inevitable obstructions of air resistance and the flexing of the spring. When the air pressure is reduced to three centimetres of mercury, the energy dissipated in overcoming its resistance is about equal to that consumed in flexing the spring and together they amount to ·081 centimetre-gramme per half-minute. Mr. Shortt estimates the remaining external frictions as follows:—

(1)	Sliding and rolling friction between the impulse jewel and the impulse wheel ...	0·0004
(2)	Pivot friction of wheel	0·0015
(3)	Energy stored in wheel after impulse by virtue of its spin	0·0002
		0·0021

Thus the only losses that have to be made good amount to 0·0831 centimetre-gramme per half-minute and they are supplied by a weight of 0·415 gramme falling 2 mm.

The delivery of this impulse increases the amplitude of the pendulum's swing by six seconds of semi-arc—an amount which can, of course, only be observed with the assistance of a microscope. At the end of each half-minute, the arc has fallen by that amount.

A Synchronome Shortt free pendulum and its slave are illustrated in figs. 124 and 125, page 237; they are drawn in outline and cut away in perspective to enable you to see the works. Free pendulums are customarily cased in copper cylinders strong enough to withstand the external atmospheric pressure of 15 lbs. to the square inch when the air is exhausted, and they are usually

provided with microscopes underneath the glass floor of the case to read the arc with great precision.

In observatories, a position in the basement is always selected and the chamber is kept at constant temperature by an automatic thermostat.

Greenwich Observatory is built on the site of the Castle of Duke Humphrey of Gloucester and the clock chamber may well have been the deepest of its dungeons. There are two free pendulums set at right angles to one another bolted rigidly to walls 4 ft. thick. They are Sidereal clocks, and as such their function is to assist the Astronomer to determine true time by direct readings against his star transit observations. Their rate is ascertained with the greatest care, but is not necessarily corrected; it is its uniformity that matters.

The slave clock on the other hand is usually placed in a more accessible position on the ground floor. When the rate of the free pendulum has accumulated to two seconds, plus or minus, its slave may be corrected by moving its 15T wheel one tooth forwards or backwards, thus the Sidereal free pendulum may, and should be, left untouched for years. Indeed, it is only by leaving it alone that justice can be done to its remarkable uniformity of rate, since the closest observation for several months is required to prove that any deviation has occurred.

But when a free pendulum is used to measure mean Solar time, it is necessary to regulate it as closely as possible, particularly if the clock is used to transmit wireless time signals. To achieve an absolute zero rate would be as difficult as balancing a billiard ball on the edge of a razor, and since that cannot be done, it is necessary to provide means for correction. For this purpose, the method of magnetic correction originated by Sir George Airy is adopted, a permanent magnet being attached to the bottom of the pendulum with a coil of wire fixed on the floor of the case immediately underneath it so that the force of gravity may be diminished

or increased by the application of a small current in either direction.

There is something anomalous in correcting a clock of such precision. One has to consider carefully the reliability of the standard to which you are setting it since it is probable that that free pendulum itself is actually the better time-keeper of the two. Its rate line on the time-chart may not be horizontal, but it is probably straight. Frequent and slavish correction merely prostitutes the clock to the level of the standard, whatever it may be. The only safe rule is to apply the correction in *uniform* homœopathic doses at infrequent and *regular* intervals.

At Greenwich Observatory a third free pendulum is used to control the Mean Time installation. It is housed in the little domed building in the courtyard which originally contained the telescope presented by Sir George Shuckbergh in 1811 but which was found unsuitable for the purpose. It makes an excellent home for the new Mean Time family, and it is here where the Mean Time free pendulum and its special slaves transmit the Rugby Time Signals and the six dot seconds.

The Mean Time free pendulum is not altered unless at least two comparisons have been made with the Sidereal standard and then some judgment is used when correcting. The Admiralty's monthly "Notice to Mariners" gives a daily list of errors or discrepancies in the time signals as received by wireless from Rugby, Annapolis, Bordeaux, and Nauen, which incidentally reveals the marked superiority of the Greenwich signals.

CHAPTER XXX

THE PERFORMANCE OF THE FREE PENDULUM

IN this chapter, I wish to discuss the performances of the Synchronome Shortt Free Pendulum and its possible contribution to scientific astronomy, but I cannot do so without a preliminary word as to the way in which an astronomer uses a clock, its place in the process of time determination, and the method of comparing it with the *speed of rotation of the earth*, which is our ultimate standard of time. We use the earth as the clock by which we check the free pendulum, and we have to assume its speed is constant, if only for the reason that you cannot conveniently compare the rate of two moving bodies without assuming that one is regular and is capable of being represented by a straight line—a datum line against which the variations of the other can be plotted.

The comparison is made in the first place by means of a chronograph consisting of a moving paper chart on which pens draw a continuous line until deflected by electro-magnets. One set of deflections, or dashes, made by one pen represents the beats of the clock and the other pen records the star transits. The distance between the records can be compared at leisure on this chronograph record and a time chart prepared, a straight horizontal line being drawn through the middle representing zero time, with seconds divisions above and below, in which are plotted the errors of the clock, fast or slow, day by day.

It will be obvious that this method debits the clock with the whole blame for whatever differences appear. If the astronomer made a mistake of, say, half a second in pressing the button when one of the so-called "clock"

stars crossed the spider's web in his telescope, the metho we have described would automatically debit the cloc with the error.

Human frailty and mechanical imperfections of th telescope and its mountings combine to undermine th accuracy of individual stellar observations, but the: imperfections were not apparent until the clocks wer improved.

Realisation of this was slow. It began by averagin a number of transits before ruthlessly debiting the cloc with all and every difference between it and so-calle "Time," that is to say, the astronomer's daily report c the speed of rotation of the earth, and allowances wer made for the difference in the "personal equation" o observers in the effort to smooth out the clock rate But it was not until early in this century that a true sense of proportion and relative accuracy in the processe of time measurement began to assert itself.

From 1911 onwards wireless telegraphy compared with instantaneous and irrefutable accuracy, the tim determinations of distant observatories and put it unerring fingers on the weak spots in our existin methods. It was realised that there are three essentia elements in time determination, transit observations the clock, and the chronograph, and that they requirec tuning up to meet modern requirements.

Just as improved shell-resisting armour produces a bigger gun and the bigger shell is met by thicker plate so the improvement in any one of the processes in time measurement demands a corresponding improvement in the others, and reacts upon itself.

Unaided transit observations, coarse in detail but accurate in bulk, were all we had to check our clocks by; then wireless time signals arrived, and, by revealing discrepancies in the time determinations of distant observatories, made both the transit records and the clocks look rather foolish.

The means of comparison surpassed the instrumental

accuracy of clocks and telescopes. That horse shot ahead in the race and seems destined to remain in front in the field of science, since wireless rhythmic signals are equal to any possible requirements. In the meantime, the introduction of the "impersonal micrometer" greatly improved transit observations and left the clocks a bad third.

You have seen the clock advance, and if you have not experienced some of the thrills of the Derby or the Grand National whilst watching its sudden dash to the front, then I have failed to impart the spirit of the chase. I have always said that the reward lies there rather than in the achievement.

The first free pendulum was erected at Greenwich in November, 1924. It was adopted as the Sidereal standard for the Observatory from January 1st, 1925. This foretaste of its mettle was such that it received at once the signal honour of reversing the normal method of charting. Its rate having been determined during the first six weeks' run, it was forecasted and represented by a smooth line carried forward for some months and the transit observations were plotted as a zig-zag on each side of it. That method has been adopted ever since, it being realised that no single transit observation, nor even a group of transits, averaged, can say at any moment that the clock is wrong; they can only indicate a slight deviation from the forecast as a result of months of observation.

Transit observations being coarse in present detail, but accurate in ultimate average bulk, it follows that it is of great advantage to have two or more free pendulums running together and frequently compared. When you have two clocks running for some months within one-hundredth of a second of each other, you can confidently repudiate the suggestion that you are out by one-tenth of a second at any point, and the individual transit observation graciously accepts the blame.

This comparison must be carried out with a degree

of accuracy distinctly greater than the error it is required to reveal, and since the maximum change of rate discoverable in a Shortt free pendulum clock in any one day is of the order of 0·003 sec., no ordinary chronograph can be expected to handle such a small space of time. Relays and pen magnets require great care to achieve a constancy in lag of the order of 0·01 sec.

The speed of the chronograph chart being known, the spaces between the marks are the measure of time elapsing between the events. The limitations of this method are obvious; small intervals of time can only be measured by reeling out the paper at a high speed, and that implies an enormous waste of stationery. The only continuously moving element is the paper.

This horse has dropped far behind in the race and you will need your field glasses to see it coming round the bend.

But in 1928, Mr. A. L. Loomis, of Tuxedo Park, New York, invented a chronograph of an entirely

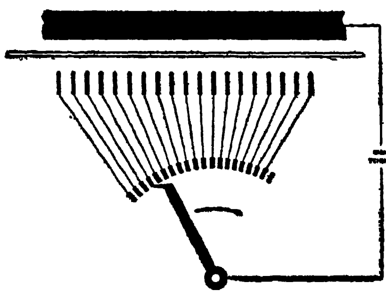


Fig. 123.

different type, in which another continuously moving element is introduced, in addition to the paper.

His chronograph propels a paper chart in the ordinary way, and the chart is unusually wide, about 10 in. It passes over a metal comb with 100 upstanding insulated teeth, each one of which is wired to a segment of a commutator. (Fig. 123). A rotary contact arm revolves

in this commutator at a speed of 10 revolutions per second, with the result that every tooth in turn along the length of the comb provides a path for an electric current. When the Synchronome remontoire of each free pendulum operates, it makes use of whichever of these paths is open at the moment, and discharges a spark through that tooth of the comb which represents that particular one-thousandth part of the second at which the clock has arrived. The spark pierces the paper on its way to a horizontal bus-bar immediately above it.

Thus the time-spacing is accomplished transversely across a band of paper 10 in. wide, of which every one-tenth of an inch represents the one-thousandth part of a second. The forward progression of the paper may also be considered as time-spacing, but it is quite slow, about a quarter inch per half-minute, which is sufficient, since the records of each free pendulum are always at 30 secs. interval.

Throughout the long reign of the Graham dead-beat escapement, the only way in which the clock could record itself was by means of a contact applied to its 'scape wheel. That was vicious, not only, nor mainly, because the contact making of its benighted age took all its energy by highway robbery from the clock, but because of its lack of precision, since it thought nothing of putting an extra one-hundredth part of a second into one second and one short in the next.

On the other hand, the free pendulum requires no applied contact to record its performance, since the Synchronome remontoire is a switching action available for all purposes, and being taken direct off the pendulum itself, it is correct to one-thousandth of a second. This virtue was always suspected, but was not proved until the invention of the Spark Chronograph.

That is the natural result of the Synchronome switch arm falling off the pendulum into contact, and until this was described in the *British Horological Journal* of January, 1906, the possibility of taking precise time

mechanically from a pendulum without it being aware of it was not realised, though Rudd had done it in 1898.

Even now, in a later generation, there is lamentable ignorance on the subject, witness the many inventions which use photo-electric cells and thermionic valves for a purpose which is accomplished so much better by a robust mechanical switch.

The present position may be summed up by the statement that the clock has now achieved a steadiness of rate which it is beyond the power of transit observations to check over short periods, though, of course, the speed of the earth's rotation is its ultimate standard, whilst the chronograph, the means of recording the clock thereon, and the means of comparison by wireless telegraphy, are competent to do all that is required of them.

Thanks to this tuning up of the adjuncts to time measurement—these improvements in our tools—it has been possible to investigate and diagnose with wonderful accuracy the causes of such errors as remain. The effects of secular growth of the Invar rod, the small residual temperature co-efficient, and microscopical variations in the arc of the pendulum have been segregated and evaluated as we shall see in the next chapter, in which I shall attempt a short summary of the performance of the free pendulums at Greenwich Observatory.

CHAPTER XXXI

FIVE YEARS' EXPERIENCE AT GREENWICH

AT the Royal Astronomical Society's meeting in January, 1930, at Burlington House, Dr. Jackson described the performance of the Synchronome Free Pendulums, known as the "Shortt" clocks, in Greenwich Observatory, for the year 1929. Three have been installed there successively in the years 1924, 1926, and 1927. Dr. Jackson's review of their performance is becoming an annual event much looked forward to by astronomers.

On a similar occasion in January, 1929, Dr. Jackson said: "It seems that we are getting to the stage in which we can compare the lengths of two successive years to one second of time." And after an analysis of the performance of the clock for the year 1929, he says: "The conclusion to be drawn from this paper is that hopes of checking the regularity of the earth's rotation from the free pendulum have considerably increased."

This hope is based upon a study of the clock and its performance as it is. I have to consider the possibility of its further improvement.

In the first place it cannot be too clearly understood that it has been necessary to put the whole performance of the clock under the microscope in order to discover any error at all.

Anyone with a life-time's experience of the best astronomical clocks hitherto known would say, as Professor de Sitter, of Leiden, said when he first saw the record of the free pendulum at Greenwich Observatory in 1927, "its rate is absolutely invariable."

Yet it is by no means perfect. It is ordained that perfection shall be elusive, and since the joy is in the

chase rather than in the achievement, we must not rebel if the golden apple is held just beyond our reach.

The rate of the clock having been ascertained by a long series of transit observations, and its performance forecasted on a chart by a straight line at a certain inclination, then a further long series of transit observations during the next few months will show that changes of rate have occurred, sometimes amounting to as much as one two-hundredth of a second per day.

In our search for the cause of these variations, we observe that the arc varies and until the causes of these variations are ascertained and cured, the work of the clockmaker is not done.

Circular error has usually been assumed to be negligible in such small arcs as we employ, but where we are dealing with time measurement of the order of accuracy of one part in thirty millions, it must be taken into account.

It is difficult to see why there should be any variation of arc when the pressure in the case remains the same, *i.e.*, exhausted to about 1″ of mercury, since the impulse is imparted by the fall of a lever providing a constant weight falling a constant distance and acting upon the pendulum at identically the same phase position every time, yet changes of amplitude do occur, and have amounted occasionally to ·1 mm. in the semi-arc.

In the Synchronome Free Pendulum, illustrated with its accompanying slave clock in figs. 124 and 125, the beat plate is fixed face downwards on the extreme bottom end of the pendulum. It is read with a microscope, through the plate glass panel which constitutes the floor of the case. By this means it is possible to read to within two seconds of arc, or a hundredth part of a millimetre in a normal semi-arc of less than 1 degree or about 50 minutes or 17 mm.

Now a variation of ·01 mm. will, by circular error, alter the rate by $^{s}\cdot00145$, or $^{s}\cdot53$ in a year, so the necessity for this close observation is obvious.

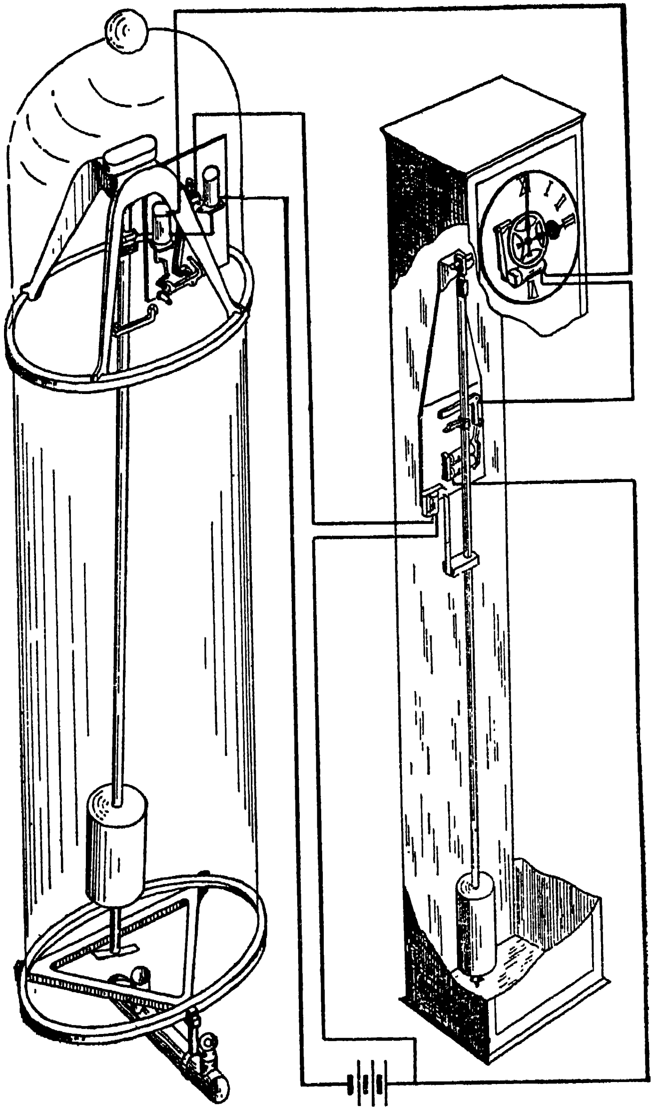


Fig. 124. Free Pendulum. Fig. 125. Slave (Type B).

Until the causes of these minute variations in arc are ascertained and cured they must be carefully observed and recorded, and their effect in circular error allowed for. That is what Dr. Jackson and Mr. Bowyer have been doing at Greenwich, and they have recounted their observations in an article, which appears in the January, 1930, issue of the Monthly Notices of the Royal Astronomical Society.

Dr. Jackson has found that by applying the appropriate correction for circular error to the past performance of the clock, its variations are smoothed out almost into a straight line. Incidentally he has measured the changes of arc and rate which result from a change in pressure. Obviously a reduction in pressure, in itself a cause of acceleration, will result in an increase of arc, which, by circular error, retards. These opposite effects are found to compensate one another exactly at a pressure of ·74″ of mercury.

This ability to isolate the circular error and to apply its theoretical calculated effect as a correction to the rate of the clock implies the elimination of practically all other sources of variation, or at any rate the identification and measurement of whatever residual causes of irregularity may remain, such as the secular growth of the rod and its temperature error.

It is only by means of this prolonged and critical study of the performance of the clock that it has been possible to analyse these residuals and allow for them, but having done so, variations of arc give direct readings for correction of rate.

This is a notable advance, not so much in the going of the clock as in the understanding of its performance.

None of these small residual causes of irregularity could be diagnosed in an ordinary clock; they would be completely masked by escapement errors. This success of the analysis at Greenwich is born of faith in the free pendulum and its freedom from all the ills that clocks are heirs to, and this faith is growing.

But until we can find the cause of these minute variations of arc, we cannot rest content. A song of triumph would be inappropriate; let us rather face the fact that all we have done so far is insufficient.

It is not enough that we have removed all interference with the pendulum excepting only that involved in giving impulse to it, because we have to admit that owing to human imperfections the impulse is not absolutely invariable (although the most invariable thing we can conceive of, viz., a constant weight falling a constant distance).

It is not enough that we have reduced the period during which interference takes place to one part in 100 of the time measured by giving a concentrated impulse every half-minute instead of a prolonged one every second, although this enormously reduces the proportion of the one variable element, pivot friction.

It is not enough to divide this force (and with it this vice of its variability) by *five*, which we do by putting the pendulum in vacuum, incidentally removing every kind of barometric error.

It is not enough that we perform the self-winding, switching and time-counting operations with a certainty and precision which is unassailable and will build up unbroken records for years.

It is not enough to apply the impulse to the pendulum at such a point in its path that its variations will not affect its time-keeping, the clock being innocent of anything in the nature of escapement error, because variations of arc will occur (albeit discoverable only by a microscope) and variations of arc bring in the circular error.

Mr. Shortt showed us in 1910 how to introduce an escapement error with opposite sign to circular error by means of his inertia escapement, but we must not be content with palliative measures; it is for us to find the causes and eliminate them.

In the meantime, Dr. Jackson and Mr. Bowyer come

to the rescue. They say, in effect, "all other errors having been eliminated or evaluated, we can watch the arc microscopically and apply a correction for the circular error."

That is the position after five years' experience of the free pendulum at Greenwich, and it indicates that the clock can keep time to within a second in a year on its own dead reckoning.

It also gives ground for hope that when two or more, set going in the same group, are closely compared and their performances studied with the same care, they will throw light upon hitherto unsolved problems, such as the discrepancies between the period of rotation of the earth, and the motions of the moon and other members of the solar system.

CHAPTER XXXII

CONCLUSION

HAVING shown how time can be measured with an accuracy of one second in a year, the layman asks, "What is the use of it? Are we any the better off?" No question can be better calculated to rouse the wrath of scientists, those seekers after truth who are always exploring the hidden mysteries of nature and for whom accurate measurement is the first article of their creed. They acclaim an achieved precision of one part in thirty millions—less than one second of time in a year—with a respect which amounts almost to reverence.

Achievements in pure science frequently lie unused for years, merely adding to the general store of knowledge until some further detail is evolved which galvanises the whole into a great and beneficent invention. This achievement is more fortunate, since it has an immediate, if limited, application. I refer, of course, to astronomy. Time determination is the first duty of an observatory; it may be said that Greenwich was established for that purpose.

An accuracy of the order referred to surpasses the wildest dreams of the astronomers as to the capabilities of a clock, and we have seen how they now confidently expect it to throw some light on hitherto unsolved problems. The Nautical Almanac for 1931 points out how this new standard of accuracy demands the revision of the absolute standard of time itself, which in the past has been known as Sidereal Time, but must now take into account nutation, and will in future be known as Average Sidereal Time. This nutation error, amounting to ·003 second per day, at maximum, must be debited somewhere. The clock will not accept the soft im-

peachment, so the British Admiralty has had to alter its Time Standard.

But the practical man's question is still insistent. Is not a wider use of the invention possible? Are the scientists and astronomers alone to reap the benefit?

The root idea of a Free Pendulum is the employment of a slave clock, running in harness with it, to perform its escapement function for it. That involves a construction and a cost prohibitive in a commercial article; from its very nature and the nature of its job its use is limited to observatories.

Can it not be produced in some simpler form—as a practical application to some useful and homely type?

It is one thing to break the world's records for accuracy of time measurement, and quite another thing—and from some points of view a greater thing—to raise the standard of time-keeping of the general public by providing the community with more accurate clocks.

The only way in which the slave can be dispensed with is by applying a contact to the master pendulum itself *which then ceases to be free.*

I see no way out of this impasse except by very slightly lowering the high standard we have set ourselves. In a commercial clock I am prepared to take a little energy out of an otherwise free pendulum, provided the following conditions are rigorously observed.

The disturbing force must begin with extreme gentleness, increasing to its maximum when the pendulum is in the middle of its swing and ending with equal gentleness, the increase and diminution being equally disposed on each side of zero. The solution I offer is a magnetically operated contact as illustrated in fig. 126. It provides a simple and reliable means of performing the time-counting and releasing formerly done by the wheel of 15 teeth illustrated in figs. 88, 94, 99, 119, and 121. This is the only construction I can conceive of that will meet these conditions. Anything in the nature of a mechanical contact is ruled out as incompetent to

fulfil them. The point of a wire passing through a globule of mercury is ruled out on the grounds of unreliability and photo-electric cells and thermionic valves are ruled out on the ground of complexity (see Chapter XVIII).

But in the suggested arrangement, one of the contact springs is provided with a little armature of soft iron and is drawn down into contact when the permanent magnet passes underneath it. Being mounted in a small glass tube in which hydrogen is substituted for air, it is confidently used to pass one tenth amp. at four volts for, say, one tenth of a second every second indefinitely. The seconds impulses so originated operate a dial movement of the type described in Chapter XVI, and the thirtieth impulse is shunted through the magnet to withdraw the catch supporting the gravity lever of the Synchronome Remontoire.

You may wonder that I should propose magnetic interference with a pendulum after all the hard things I have said of Wheatstone's induction method, but he attempted to make his pendulum generate sufficient power to *drive a group of dials*, whereas we now only want enough to release a Synchronome switch—not even that—but only enough to make a contact which shall enable a dry cell to release it.

The all-important thing we want to know is the extent of this interference, and fortunately it is quite easy to make a complete analysis of the forces we are handling.

There are two ways of doing it, for we can approach the problem from either end. We know the energy required to maintain an absolutely free pendulum at a constant arc by multiplying the weight of the gravity lever by its fall, and we note the rate at which the pendulum dissipates its energy by observing the dying down of the arc when we deprive it of its impulses.

By a simple process of trial and error we can ascertain exactly what increase in weight in the gravity

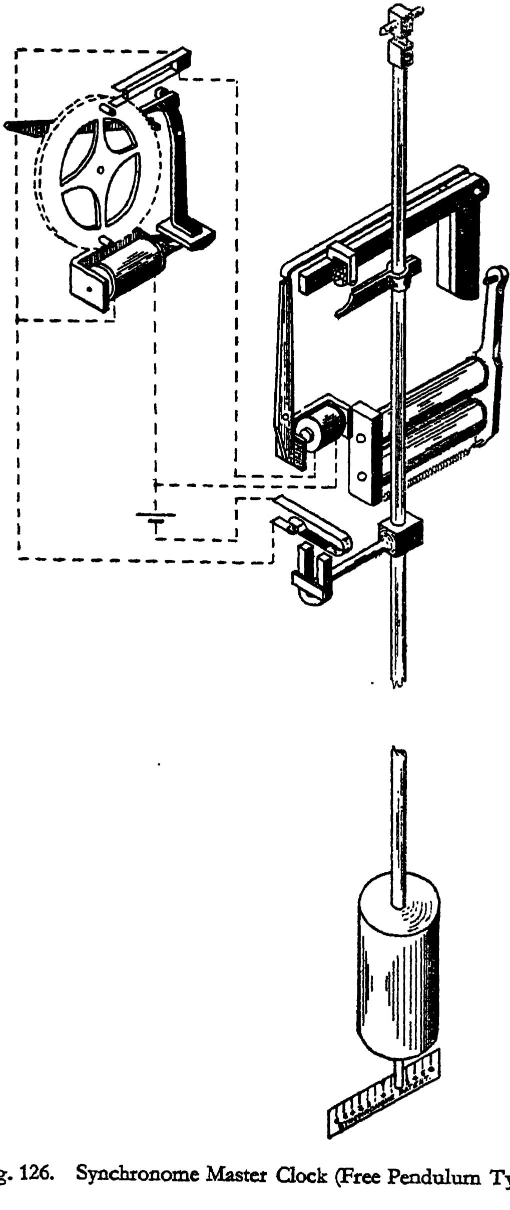


Fig. 126. Synchronome Master Clock (Free Pendulum Type)

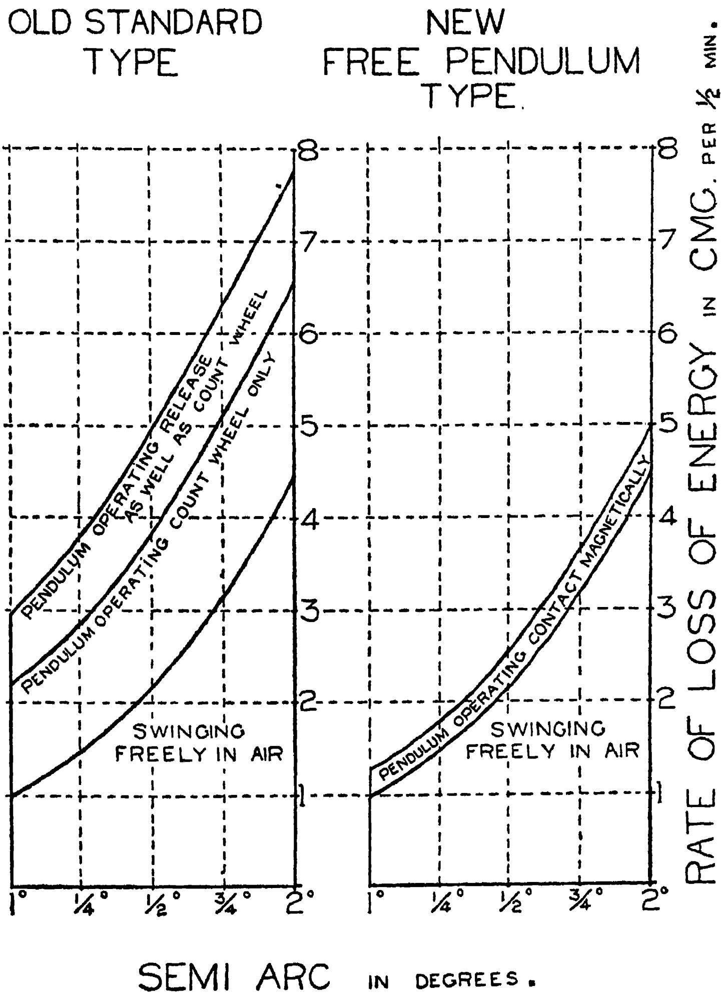


Fig. 127. Curves showing loss of energy.

lever is required to maintain the same arc when the pendulum is performing the mechanical operations of gathering the 15T wheel every two seconds, and releasing or unlatching the gravity arm; and when it is carrying a permanent magnet past an armature on a

contact spring every second; and we can check our figures by noting how long it takes to die down from one arc to another under each of these conditions.

These energy curves are given in the form of graphs (fig. 127).

To maintain an absolutely free pendulum at a semi-arc of 40 mm. (*i.e.*, a total arc of about four degrees, which is customary in the commercial Synchronome standard Master Clock), 4.5 cm.-gm. per half-minute is required. This is almost entirely expended in overcoming air resistance. Smaller arcs will, of course, require less energy, and you will observe that for half the swing (20 mm. plus 20 mm.=2 degrees) 1 cm.-gm. per half-minute will suffice.

The mechanical gathering of the 15T wheel requires 2.05 cm.-gm. per half-minute.

The mechanical releasing of the gravity arm requires 1.1 cm.-gm. per half-minute.

The addition of my magnetic contact requires .45 cm.-gm. per half-minute, an increase of only one tenth of what the pendulum requires to overcome its air resistance at a semi-arc of 2 degrees.

Thus the mechanical operations require 3.15 cm.-gm. as compared with the magnetic contact, which takes only one seventh of the energy, viz., .45 cm.-gm.

It is very satisfactory to be able to analyse these forces since it is impossible to do so in any other kind of escapement. Take, for instance, a dead beat, a half dead beat, or anchor escapement. You cannot say how much of the energy produced reaches the pendulum and how much is lost in friction. There is no way of disintegrating it, since impulse and friction are coincident and continuous.

It has hitherto been impossible to indicate seconds on a Synchronome Master Clock in its simplest form, since it is limited to steps of two seconds and the dial cannot be centrally placed. This new method, how-

ever, lends itself to the production of a popular self-wound clock provided with centre-seconds dial, capable of acting as a Master Clock if desired, and applicable to pendulums of any length, even half-seconds.

In order that the dial on the Master Clock may serve as a pilot representing the time-circuit, its minute and hour hands are driven by a half-minute electrical impulse dial movement in series with all the rest. The seconds hand on the inset circle has its own impulse movement, and the driving of it is the only duty of the magnetic contact, except that once every half-minute the release magnet is also operated.

It is to be observed that this secondary contact, seen behind the dial at the top of fig. 126, which merely selects the thirtieth second, is never closed or opened alive, and if by any mischance the seconds dial was to be wrongly set or missed a beat, it would automatically set itself right by what may be called a "phase-corrector."

The release takes place when the top corner of the impulse curve is just arriving under the roller, the pendulum travelling from left to right. If the dial was one beat out of phase, then it would occur when the pendulum was travelling in the opposite direction, and the roller would fall upon the dead surface of the impulse pallet. By the simple expedient of dividing the pallet into two insulated halves, an extra impulse is transmitted to the dial movement which corrects its phase.

This clock was the subject of a lecture at the British Horological Institute in November, 1930, and readers who wish to know how the circular and barometric errors are dealt with are referred to the *Horological Journal*.

In my opening chapter I promised to take you along the road through which the idea of applying electricity to clocks had wandered or progressed, to lead you down the primrose paths of pleasing mechanical and electro-mechanical devices, just far enough to show you the inevitable blind alleys, and then take you up and over

the hills of difficulty to the straight road of scientific principles to bring us to our goal.

There has been such a lot of futile wandering on the part of inventors that it has not been easy to tell it in a consecutive story of evolution and development, but I claim to have fulfilled my promise.

The clockmaking profession has remained too long under the stultifying influence of tradition and the dogmas of their text books, and I trust that the Free Pendulum, both in its academic and its commercial form will be a spur to further research and development.

GLOSSARY

Explanation of simple electrical terms for clockmakers

THE DEFINITIONS OF ELECTRICITY

Resistance.—The measure of the opposition offered to the flow of an unvarying direct current through a wire, dependent upon its composition, cross sectional area and length. Symbol R.

Ohm.—The unit of resistance. Symbol Ω formerly ω.

Ampere.—The unit of rate of flow of an electric current. Symbol I.

Coulomb.—The unit of quantity of an electric current; 1 ampere flowing for 1 second.

Watt.—The unit of electrical power—the rate of doing work. Symbol W. 746 watts are equivalent to one horse-power.

Volt.—The unit of electrical potential or pressure, and a measure of Electro Motive Force. Symbol E.

Ohm's Law.—The relationship between electrical pressure, resistance and current, whereby when any two are known, the third can be ascertained. Symbol

$$I = \frac{E}{R}; \quad E = I \times R; \quad R = \frac{E}{I}$$

Micro-farad.—The practical unit of the capacity of two plates or wires separated by an insulator for holding a charge of electricity. Symbol C.

Self-Induction.—The electrical equivalent of inertia, the energy required to overcome the opposition to the passage of a current by, say, a coil of wire wound round an iron core.

Inertia.—The mechanical equivalent of self-induction. A measure of the energy required to start a body moving from rest, or to change its speed of motion.

THE SOURCES OF ELECTRICITY

Leclanché Cell.—A primary voltaic cell employing carbon (positive) and zinc (negative) electrodes, and a solution of ammonium chloride (sal ammoniac) as the electrolyte; E.M.F. 1.4 volts. This type of cell is generally unsuitable for electric clocks on account of its high and fluctuating internal resistance and the frequent attention required to keep it in condition.

Dry Cell.—Usually of the Leclanche type, but having the sal ammoniac solution in the form of a paste, the cell being thus unspillable can be made up in convenient and portable form. E.M.F. 1.5 volts. Recommended for electric clocks on account of its comparatively constant output and the fact that it requires no maintenance.

Storage Cell.—A secondary cell depending upon a reversible electrochemical action and reaction of its elements. The positive element or plate is usually of lead oxide, whilst the negative plate is of pure lead, the electrolyte being a solution of sulphuric acid. Some types of storage cells employ Nickel & Iron (Ni & Fe), in an alkaline solution.

Electrolyte.—The exciting liquid of a voltaic cell.

Battery.—A number of cells connected in series or parallel or series-parallel. (See the Distribution of Electricity).

Direct Current.—A source of electricity of constant direction or polarity. Symbol D.C. Can be used for operating circuits of elec-

trical impulse dials, or for charging storage cells.

Alternating Current.—A source of electricity whose direction or polarity is constantly changing from positive to negative and vice versa. Symbol A.C.; cannot be used, as produced, for operating circuits of electrical impulse dials nor for charging storage cells. (See "Rectifier.")

Frequency.—The rate at which an alternating current changes its direction. A common frequency is 50 complete changes or cycles per second. Symbol ∞.

Rectifier.—An instrument for converting A.C. to D.C.

THE DISTRIBUTION OF ELECTRICITY

Switchboard.—A group of switches, fuses, and measuring instruments, etc., used for controlling an electric power supply such as the charge and discharge of storage batteries.

Series Circuit.—The joining up, or the arrangement of a number of coils or instruments end to end. The whole of a current (applied at each end of the group) has to pass through each instrument successively.

Parallel Circuit.—A number of coils or resistances joined up so that the respective ends of each are all connected to the same terminal of the battery. A current applied to such group will divide and a portion of it traverse each coil separately.

Series Parallel Circuits.—Two or more series circuits joined together in parallel.

Back E.M.F.—A pressure generated in a coil of wire as a result of its own induction. It is of opposite sign to the main current. The returning or giving up, on stopping the current, of that energy required initially to start it flowing against the opposition of self-induction.

Non-inductive Shunt.—A bye-pass resistance of negligible self-induction connected in parallel with, say, a coil or magnet to short circuit the back E.M.F. and prevent its dissipation in the form of a harmful spark at the contacts.

Short Circuit.—A path of low electrical resistance.

Permanent Magnet.—A piece of steel usually of horse-shoe shape which retains its magnetism.

Electro-Magnet.—A piece of soft iron wound with insulated wire in the form of coils.

Core.—The centre portion of an electro-magnet over which the wire is wound; usually of soft iron.

Yoke.—The framework, usually of soft iron, of an electro-magnet which together with the core forms a complete "magnetic circuit" with the armature.

Armature.—A piece, usually of soft iron, in which mechanical energy can be produced by a magnetic force.

Commutator.—A device for conducting current to a brush or wire successively from other wires or sources of current. It consists of a number of sections or segments insulated one from the other and built up usually in the form of a disc or drum.

Condenser.—A pair of metal plates or electrodes (separated by an insulator) possessing capacity and thereby acting as a reservoir which may be used instead of, or in combination with, a non-inductive shunt to absorb the "spark at break."

Explanation of simple horological terms for electricans

Air Resistance to the swing of a pendulum is such that it requires nearly four times as much energy to maintain it at a normal arc in atmosphere as it would in a vacuum, when it would then go 9½ secs. per day faster.

Arc.—The portion of a circular path in which a pendulum swings, usually limited to a few degrees of the complete circle.

Barometric Error.—The effect of changes in air pressure on the rate of a pendulum.

Beat Plate.—The scale on which to observe the arc of a pendulum. If the extreme end of a seconds pendulum is 45″ from its suspension, the degrees engraved on the beat-plate will be .787″ or 20 mm. apart.

Chronograph.—An instrument which measures and records precisely short intervals of time.

Circle.—Is divided into 360 degrees, each degree is divided into 60 minutes, and each minute into 60 seconds.

Circular Error.—The longer time which a pendulum will take to cover a larger than a smaller arc.

Elinvar.—An alloy whose elasticity us unaffected by temperature.

Escapement.—The mechanical means by which a pendulum releases and receives its maintenance, *i.e.*, the power from a train of wheelwork which drives it.

Escapement Error.—Systematic disturbances of the pendulum by 'scape-wheel teeth or gravity arms which are subject to frictional variations.

Free Pendulum.—A pendulum which has nothing to do but swing.

Gravity.—The attraction of the earth, which causes the pendulum to swing when once it has been set in motion.

Interference.—A term which is used to indicate anything which interferes with the freedom of the pendulum, excepting only gravity and air resistance.

Invar.—An alloy of nickel and steel, having a very small temperature co-efficient of expansion.

Mean Solar Time.—The practical standard based on the average length of a day, and calculated from Sidereal time.

Sidereal Time.—The absolute standard which is based on the exact time of rotation of the earth, now corrected for Nutation.

Pendulum.—The length of a pendulum between point of suspension and centre of oscillation (almost equivalent to the centre of gravity of the bob), is:—

Beating seconds, 39.14 inches; beating half-seconds, 9.78 inches.

Remontoire.—Automatic re-winding at comparatively short intervals.

Temperature Error.—The effect of changes of temperature upon the length of a pendulum.

Transit Instrument.—A telescope mounted in bearings for turning North and South only for observations of the exact time of passage of the "clock" stars.

Zero.—The position in which a pendulum comes to rest under the influence of gravity: the middle of its swing.

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